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GUGGENHEIM AERONAUTICAL LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY

A STUDY OF THE EFFECTS OF RAPIDLY APPLIED LOADS AND REPEATED LOADS ON COUNTERSUNK RIVETED JOINTS

Thesis by

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and
Lieut. William E. Ditch, USN

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I. SUMMARY

A number of tests were conducted at Daniel Guggenheim Aeronautical Laboratory to determine the effects of rapid loading and repeated rapid loading on countersunk riveted joints. This investigation was conducted to indicate the importance and possibilities of future study in this field.

The rapid loading test results are compared to slow loading tests and to ANC-5 and Aircraft Industries Association of America values.

A hydraulic testing machine designed for these specific tests was constructed and placed in operation. A general discussion of the testing machine and its operation is included.

II. INTRODUCTION

The published data on the behavior of riveted joints under repeated loads is still very meager, and the method of testing joints under repeated loads has not been standardized. A preliminary study of the available tests showed that the time interval required to apply the maximum load to a test specimen has not been considered important; this assumption made by other investigators has risen from fatigue test procedure in which the rate of loading has been found unimportant. Fatigue tests are usually run at relatively low stresses, below the yield strength of the material, and in such cases the rate of loading apparently does not affect the strength of the joint. In riveted joints local stress conditions may be above the yield strength of the material and the time interval required to apply the load becomes of great importance.

The purpose of this investigation was to determine the effects of a rapidly applied load upon the strength of a countersunk riveted joint, and to determine the life of such a joint under repeated rapid loadings. Realizing that an aircraft frame cannot be subjected to true shock loads, but that it is subject to rapidly applied loads with a finite rate of loading, an effort has been made to test with rapid loading but not shock loading.

III. TEST SPECIMENS

The riveted test specimen established for this study consisted of a simple butt joint with a joint backplate one gauge thicker than the sheet. The rivet pattern consisted of single rows of three rivets placed symmetrically on each side of the joint. See figure (1) for dimensions of a typical flush riveted specimen.

Several types of test specimens were considered, and the above type joint was selected for several reasons. Realizing that this study would contain a large number of uncontrolled variables, such as workmanship and tolerances, it was felt a joint that would assist in averaging the results would be advantageous. Assuming that half of the total permanent set of the joint is due to each half joint (i.e., the single lap joint) a certain averaging could be obtained. The use of three rivets in a single row in each half of the butt joint and following through with the assumption that half the butt joint would be responsible for half of the permanent set of the joint, further averages the resulting permanent set in that each rivet is assumed to deform the same as all other rivets in the joint.

The selection of the single rows of three rivets was also influenced by the desire to correlate results with A.I.A.A., Airworthiness Project 12, (Ref. 3), who for the

most part had used a single row of three rivets in a lap joint. The butt joint selection was also felt to be more representative of aircraft construction.

All specimens are identified by coded dash numbers. The permanent dash number is divided into two parts; the first digit signifies the nominal diameter of the rivet in thirty-seconds of an inch, and the remaining digits signify the thickness of the countersunk sheet in thousands of an inch. The letter following the dash denotes the manufacturer of the specimen and the remaining digits represent the specimen number. Thus, 451-G6 signifies a 4/32 or 1/8 inch rivet, countersunk in a 0.051" sheet, manufactured by Guggenheim Laboratories, C.I.T., and the sixth such specimen furnished.

Materials chosen for these specimens are as follows: (1) Sheet material is of 24S-T aluminum alloy. (2) Rivets are 100° flat head rivets of A17S-T aluminum alloy.

Detailed drawings and the specifications of the test specimens are shown in figs. 2 and 3.

IV. LABORATORY APPARATUS

A. Description of Testing Machine.

1. Parts List for Testing Machine.

B. Time Interval to Apply Maximum Load.

C. Testing Procedure.

1. General.

2. Operation of Repeated Load Hydraulic Testing Machine.

a. Test Type--Slow Loading vs. Permanent Set.

b. Test Type--Rapid Loading vs. Permanent Set.

c. Test Type--Cycles vs. Permanent Set at Constant Maximum Loading.

A. Description of Testing Machine

The testing machine used in this study was especially designed and constructed for the tests to be conducted by the authors and co-workers of a related study. The general specifications for the testing machine as required by the problems being investigated were:

(1) Repeated loads.

(2) Rapid loading (not shock loading).

(3) Variable loading.

(4) High number of cycles and adaptability.

A mechanical testing machine was first considered but was soon discarded when it was found that the complications of removing the inertia of moving parts, repeating the same loading conditions in spite of deformation of the test specimens, and obtaining some degree of adaptability could be more easily overcome by a hydraulic testing machine.

A hydraulic testing machine, shown in figure 4 and figure 5, was then designed to provide the general requirements. To eliminate the inertia of fluid movement, the hydraulic system of the testing machine was designed in two individual parts. The primary system consisting of, and in order of flow, (see Fig. 6): a reservoir, strainer, pump, pressure regulator valve, and return to the reservoir. This primary system also contained a pressure relief

valve to take over the pressure control in event of malfunctioning of the pressure regulator valve, and an accumulator to stabilize any pressure fluctuations. This primary system was designed to operate between 75 psi. and 1000 psi., and a pressure regulator valve of such range was used. The secondary system was designed to be essentially a zero flow system and served only to transmit the pressure in the primary system to a cylinder in suitable pulsations. The secondary system consists of a solenoid operated pilot valve and the cylinder. The addition of suitable gages and a very lightly loaded check valve in the return to the reservoir line to prevent the exhausting of the hydraulic fluid from the cylinder, comprises the secondary system.

It was found advisable to provide a shut-off valve in the gage line to prevent pounding of the gage and subsequent inaccuracies. The range of loads that can be supplied by this system are 0 to 11,500 lbs. The use of different sizes of cylinders makes the range of accuracies variable. That is, the smaller the cylinder used, the greater the accuracy of the load.

The hydraulic pump is driven by a five horsepower, 3 phase, 220 volt electric motor through a reduction gear box. The electrically operated pilot valve is powered with a 110-volt solenoid which is triggered by breaker points geared to a small 110-volt motor. The hydraulic

pump motor, the solenoid, and the timing motor are controlled by separate switches, which allow a number of different type tests to be run. See Fig. 7 for electrical wiring schematic.

The general structure of the testing machine resembles a table with a lower shelf. The hydraulic pump motor, gear reductor, hydraulic pump, reservoir, accumulator, safety valve, and the strainer are positioned on the lower shelf as shown in Fig. 8. The top of the table supports the gages, electrically operated pilot valve, timing motor, breaker points, counter, pressure regulator, and switches. A 5"x5" H beam situated at the rear of the table top provides the strength member for the testing. To this beam is fastened the hydraulic cylinder. The rest of the top of the machine is available for work space. All of the hydraulic lines are placed between the shelf and the table top to separate them from the greater part of the electrical devices, a position which is readily accessible.

This testing machine rapidly applies a load to a predetermined value and holds this load for approximately one-half second. The machine is capable of repeating the same loading conditions fifty-two times a minute.

1. Parts List for Testing Machine

Name	Type
Accumulator	Vickers, 400# pressure
Counter	Veeder-Root, Large Figure
Gages	Hydraulic, Marshalltown Mfg. Co.
Gear Reductor	Boston Reductor, 3.06-1 ratio, Cat. No. HB-3
Hydraulic Check Valve	Universal, Opening pressure 1#
Hydraulic Cylinder	1.5" Diameter
Hydraulic Pump	Pesco, Gear type, Serial No. PEC-8500
Hydraulic Pump Motor	Westinghouse Induction Motor, 5 H.P., 3 phase
Pilot Valve (Solenoid)	Vickers, CK-2502-NA-220-AC-SO
Pressure Regulating Valve	Vickers CK-2502-AC-SO
Pressure Relief Valve	G5314149, 1250-1500 psi.
Reservoir	6.8 gal. capacity
Rheostat	Variable adjustment
Strainer	Cuno
Timing Motor and Gear Box	0.01 H. P. Motor

B. Time Interval to Apply Maximum Load

The time interval to apply maximum load with the one and one-half inch cylinder used was obtained with the electronic apparatus shown in Fig. 19 and Fig. 20.

Two C1 strain gauges were placed on opposite sides of the specimen and connected in series to eliminate the effects of bending. These strain gauges mounted on the specimen are shown in Fig. 17. The output of the strain gauges was amplified by the pre-amplifier and placed on the Y-axis of a Dumont 247 Oscilloscope. The pre-amplifier has a flat frequency response between seven cycles and twenty KC. A Hewlett-Packard Oscillator was used to supply a five hundred cycle wave as a time axis calibration. The Dumont Oscilloscope has a provision for the use of an external pulse to start the trace, and an initiator was constructed to trigger the oscilloscope at the instant the pilot valve was energized.

A camera attached to the oscilloscope made possible the recording of the trace obtained. Figs. 11 to 16 inclusive show the results received from the apparatus. The peaks of the time reference wave appearing in the figures are 0.002 seconds apart. The gradual reduction in the vertical height of the trace after the load has reached the maximum value is due to the decay of the pre-amplifier. Tests conducted on the same testing machine in Reference 11 with a Heiland Recording Oscil-

loscope show that the load remains constant after the maximum value has been reached. The same tests indicated that the maximum value of the load was that indicated by the primary hydraulic system pressure gage. The primary pressure gage was calibrated with the cylinder on the Riehle static testing machine. The calibration curve is plotted in Fig. 10.

The change in the time interval to apply maximum load at low and high loads is not fully explainable, but is believed the accumulator may affect the difference. The accumulator is effective at the high loads and ineffective at the low loads.

The primary reason for obtaining the Load vs. Time Traces was to insure that no value of the load existed above the load indicated by the primary hydraulic system pressure gage, and to determine to some extent the order of the time interval to obtain maximum load. The time interval to apply maximum load at a load of 500# developed by the one and one-half inch cylinder is 0.038 seconds. The time interval to apply maximum load at a load of 585# developed by the one and one-half inch cylinder is 0.013 seconds. These two loads developed by the one and one-half inch cylinder fall above and below the system pressure at which the accumulator becomes effective.

C. Testing Procedure

1. General

The results presented in this investigation were obtained with the Repeated Load Hydraulic Testing Machine described in Part IV-A. The operation of the testing machine is discussed in detail in Part IV-C2.

The general testing procedure was as follows:

(1) Verification of joint averaging assumptions as discussed in Part III by testing butt and lap joints.

(2) Determination of the effect of rapid loading by testing similar specimens with slow loading and with rapid loading.

(3) Determination of the effect of repeated rapid loads on similar specimens.

The permanent set of the joint in each test listed above was measured with a traveling microscope shown in Fig. 9, and the permanent set of the rivet was defined as half the permanent set of the butt joint in keeping with assumptions discussed in Part III.

2. Operation Procedure of Repeated Load Hydraulic Testing Machine

a. Test Type--Slow Loading vs. Permanent Set.

(1) Measure rivet joint length mounted in machine.

(2) Check timing motor for closed contacts

position.

(3) Check operation of solenoid operated pilot valve.

(4) Turn pressure gage valve ON (handle horizontal).

(5) Turn pressure regulator valve all the way counter-clockwise.

(6) Turn ON hydraulic pump motor.

(7) Turn ON pilot valve switch.

*(8) Turn pressure regulator valve clockwise until desired pressure is registered.

(9) Decrease load to zero.

(10) Turn OFF pilot valve switch.

(11) Turn OFF hydraulic pump motor.

(12) Measure rivet joint length.

(13) Repeat 6 through 12 for each desired loading.

b. Test Type--Rapid Loading vs. Permanent Set.

(1) Measure rivet joint length mounted in machine.

(2) Check timing motor for closed contacts position.

(3) Check operation of solenoid operated pilot valve.

(4) Turn pressure gage valve ON (handle horizontal).

(5) Turn pressure regulator all the way counter-clockwise.

1018

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

(6) Turn ON hydraulic pump motor.

*(7) Turn pressure regulator valve clockwise until desired pressure is obtained.

(8) Turn ON pilot valve switch.

(9) Turn OFF pilot valve switch.

(10) Turn pressure regulator valve counter-clockwise until zero pressure is registered.

(11) Turn OFF hydraulic pump motor.

(12) Measure rivet joint length.

(13) Repeat 6 through 12 for each desired loading.

c. Test Type--Cycles vs. Permanent Set at Constant Maximum Loading.

(1) Measure rivet joint length as mounted in machine.

(2) Check timing motor for "open contacts" position.

(3) Turn counter to zero.

(4) Turn pressure regulator valve all the way counter-clockwise.

(5) Turn pressure gage valve ON (handle horizontal).

(6) Turn ON hydraulic pump motor.

*(7) Turn pressure regulator valve clockwise until desired pressure is registered.

**(8) Turn OFF pressure gage valve.

(9) Turn on simultaneously both timing motor and pilot valve.

***(10) After desired number of cycles turn OFF both

timing motor and pilot valve switches simultaneously.

(11) Turn OFF pump motor.

(12) Measure rivet joint length.

(13) Repeat 5 through 12 until completion of test.

*Caution is advised in approaching a desired pressure. The pressure increase for a given movement of the pressure regulator valve increases as the pressure increases and is sensitive in the range above 400 psi, exhibiting extreme sensitivity at higher pressures. Overshooting the desired pressure may result in uncautious operation.

**Turning off the pressure gage valve prevents pounding of the gage. In extended operation it may be advisable to set the pressure, turn the pump motor OFF, allowing the pressure to return to zero, then turn the gage valve OFF. Restarting the pump motor causes the pressure to return to the valve setting, but the gage remains at zero.

***Some practice in turning off these switches at the proper moment is required, but the rhythm of the action is very obvious and a few trials will indicate the proper moment.

V. RESULTS

A. Summary of Tests Conducted.

B. Data.

1. Tables.

I. Specimen Data

II. Ultimates of Specimens

III. Comparison of Rapid Load Ultimates

2. Plots.

C. Conclusions.

A. Summary of Tests Conducted

After choosing the butt joint specimen configuration as shown in Fig. 1, the authors wished to compare the scatter of the test points with a lap joint specimen as used by the A.I.A.A. (Ref. 3), the rivet spacing and general dimensions of the joints being similar in all other respects. This test was conducted on specimens manufactured by the Guggenheim Laboratory~~s~~ by applying repeated rapid loadings of 199# per rivet. The results of this test are shown in Plot 1, in which permanent set per rivet is plotted against cycles of load applied. From the results obtained it was concluded that the butt type specimen reduced the test point scatter approximately 50%, and substantiated the assumption of the averaging ability of the butt joint.

The next series of tests were conducted to determine the effect of the time interval required to apply the load. With the testing machine as constructed, it was only possible to apply two different time intervals to maximum load. The slow time interval is obtained by manually operating the regulator valve, and the time interval to obtain maximum load is three seconds or more. The rapid time interval to maximum load is accomplished by use of the solenoid operated pilot valve, and the time interval is 0.038 seconds or less. Testing machine operating procedure for these tests is outlined in Part

IV-C2. Specimens of one rivet diameter and two sheet thicknesses, manufactured by two different sources, were tested. Two or more specimens for each type test were used to obtain average values. The results of these tests were plotted as load per rivet vs. permanent set per rivet in Plots two, three, and four. Table II is a tabular form of the ultimate values obtained from these tests and ultimate values as specified by ANC-5 and the A.I.A.A. Since ultimate values given by ANC-5 and the A.I.A.A. have a material safety factor of 1.15 incorporated, these values as shown in Table II have been corrected by this amount. Table II compares the rapid loading ultimate with ANC-5 and A.I.A.A. ultimate values corrected by the factor 1.15 as percentages of these values.

The effects of repeated rapid loadings on countersunk 1/8" rivets in 0.040" sheet was studied in the final phase of the investigation. The load per rivet was selected as 199#, which corresponds to the A.I.A.A. yield load for this rivet and sheet combination. The testing machine operating procedure for this test is described in Part IV- 2. The results of the tests on 440-G specimen are shown in Plots five, six, seven, eight, and nine in which the permanent set per rivet (e) is plotted against cycles of load (n). The results of tests on 440-D specimens are shown in Plots ten, eleven, twelve, and thirteen in which permanent set per rivet (e) is plotted against cycles of load (n).

B. Specimen Data

Key to Headings for Table I:

1. Specimen No.

   Rivet size--first digit

   Nominal diameter of rivet in thirty-seconds of an inch.

   Sheet thickness--second and third digits

   Thickness of top sheet in thousands of an inch.

   Manufactured by--letter following dash

   G--Guggenheim Aeronautical Laboratory

   D--Douglas Aircraft Company

2. Type Joint.

   L--Lap

   B--Butt

3. Type Test.

   C--Testing Machine Calibration

   F--Rapid rate of loading for Load vs. Permanent Set Curve.

   R--Repeated loads at constant loading

   S--Slow rate of loading for Load vs. Permanent Set Curve

4. Rivet Load.

   V--Variable loading (as in obtaining load vs. permanent set curve).

   ( )--Load per rivet in lbs., number signifies maximum load obtained.

5. Plot No.--Results shown in Plot stated.

Table I. Specimen Data

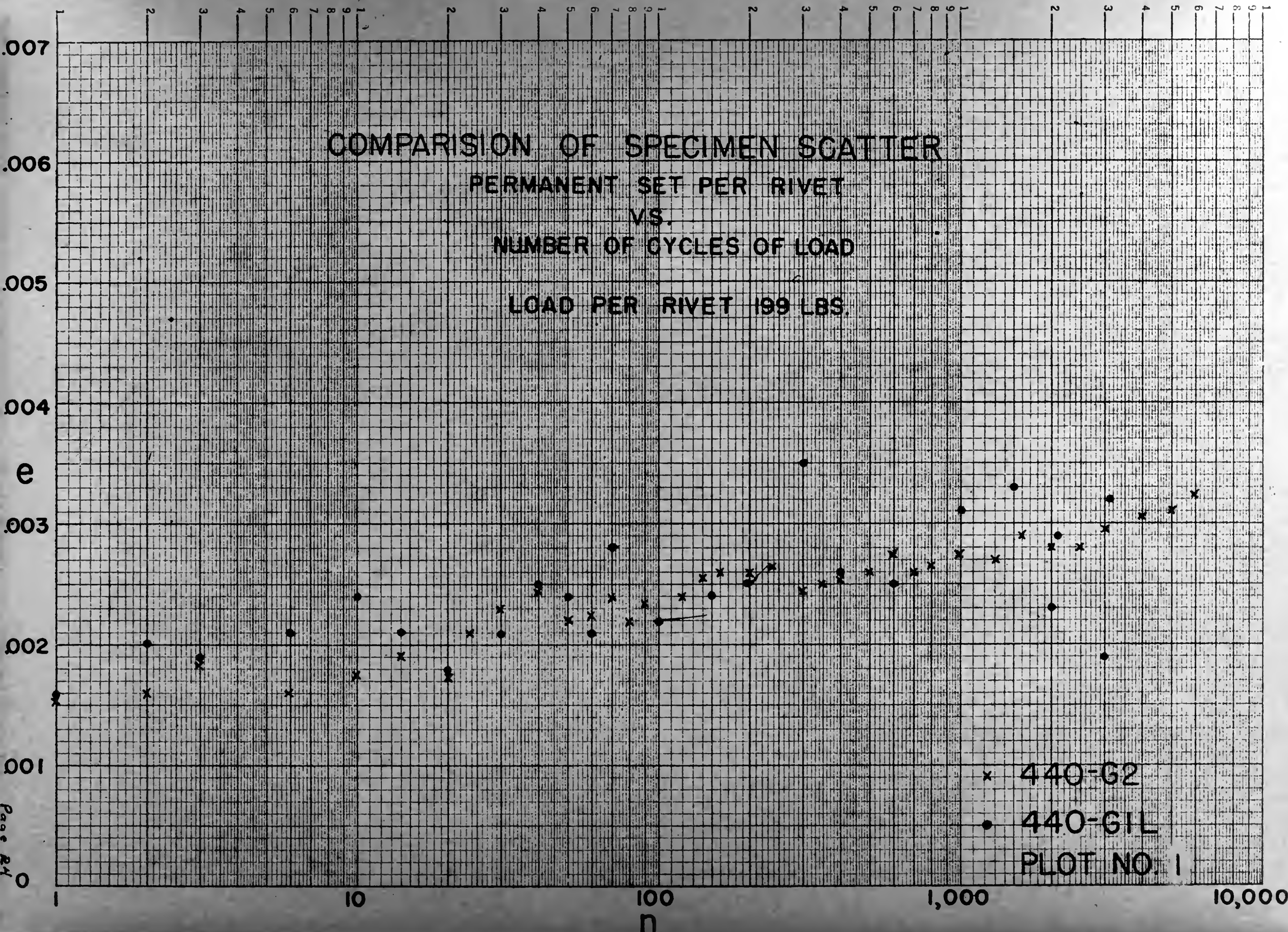
1	2	3	4	5	6
Specimen No.	Type Joint	Type Test	Rivet Load	Plot No.	Remarks
440-G1	B				Determined Testing Procedure
440-G2	B	R	199	1	Verified Specimen Results
440-G1L	L	R	199	1	Verified Specimen Results
440-G3	B	S	V	2	Effects of rate of loading
440-G4	B	S	V	2	Effects of rate of loading
440-G5	B	F	V	2	Effects of rate of loading
440-G6	B	F	V	2	Effects of rate of loading
440-G7	B	R	199	5	Effects of repeated loading
440-G8	B	R	199	6	Effects of repeated loading
440-G9	B	R	199	7	Effects of repeated loading
440-G10	B	R	199	8	Effects of repeated loading
440-D1	B	S	V	3	Effects of rate of loading
440-D2	B	S	V	3	Effects of rate of loading
440-D3	B	S	V	3	Effects of rate of loading
440-D4	B	F	V	3	Effects of rate of loading
440-D5	B	F	V	3	Effects of rate of loading
440-D6	B	C	V		Determined Load vs. Time Trace
440-D7	B	R	199	10	Effects of repeated loading
440-D8	B	R	199	11	Effects of repeated loading
440-D9	B	R	199	12	Effects of repeated loading
451-D1	B	S	V	4	Effects of rate of loading
451-D2	B	S	V	4	Effects of rate of loading
451-D3	B	F	V	4	Effects of rate of loading
451-D4	B	F	V	4	Effects of rate of loading

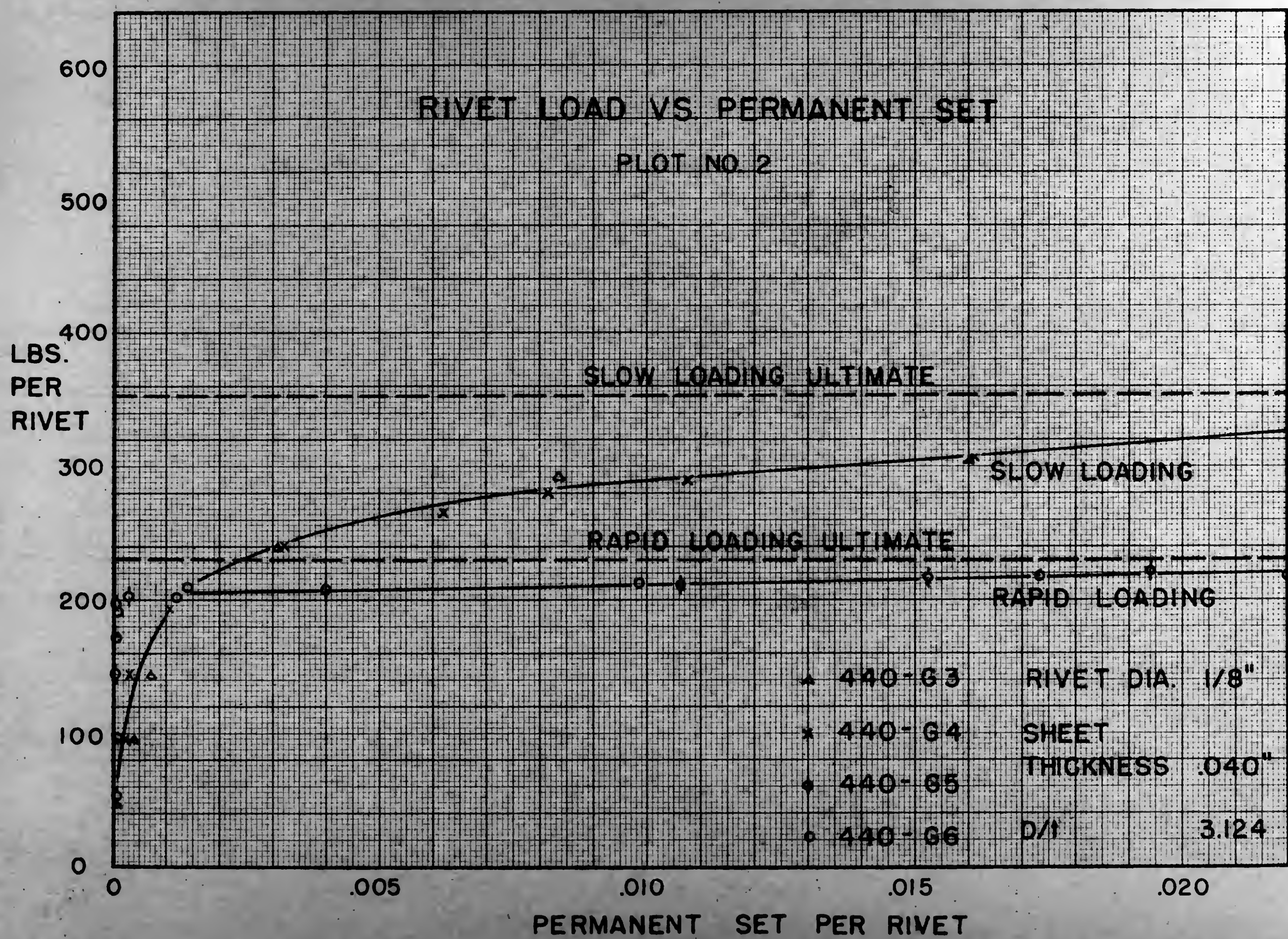
Table II. Ultimates of Specimens

Specimen	440-G	440-D	451-D
Ultimate as Tested--Rapid Loading	231 #/R	264 #/R	272 #/R
Ultimate as Tested--Slow Loading	353 #/R	463 #/R	596 #/R
A.A.I.A. Ultimate	299 #/R	299 #/R	330 #/R
ANC-5 Ultimate	271 #/R	271 #/R	331 #/R
A.A.I.A. Yield	199 #/R	199 #/R	243 #/R

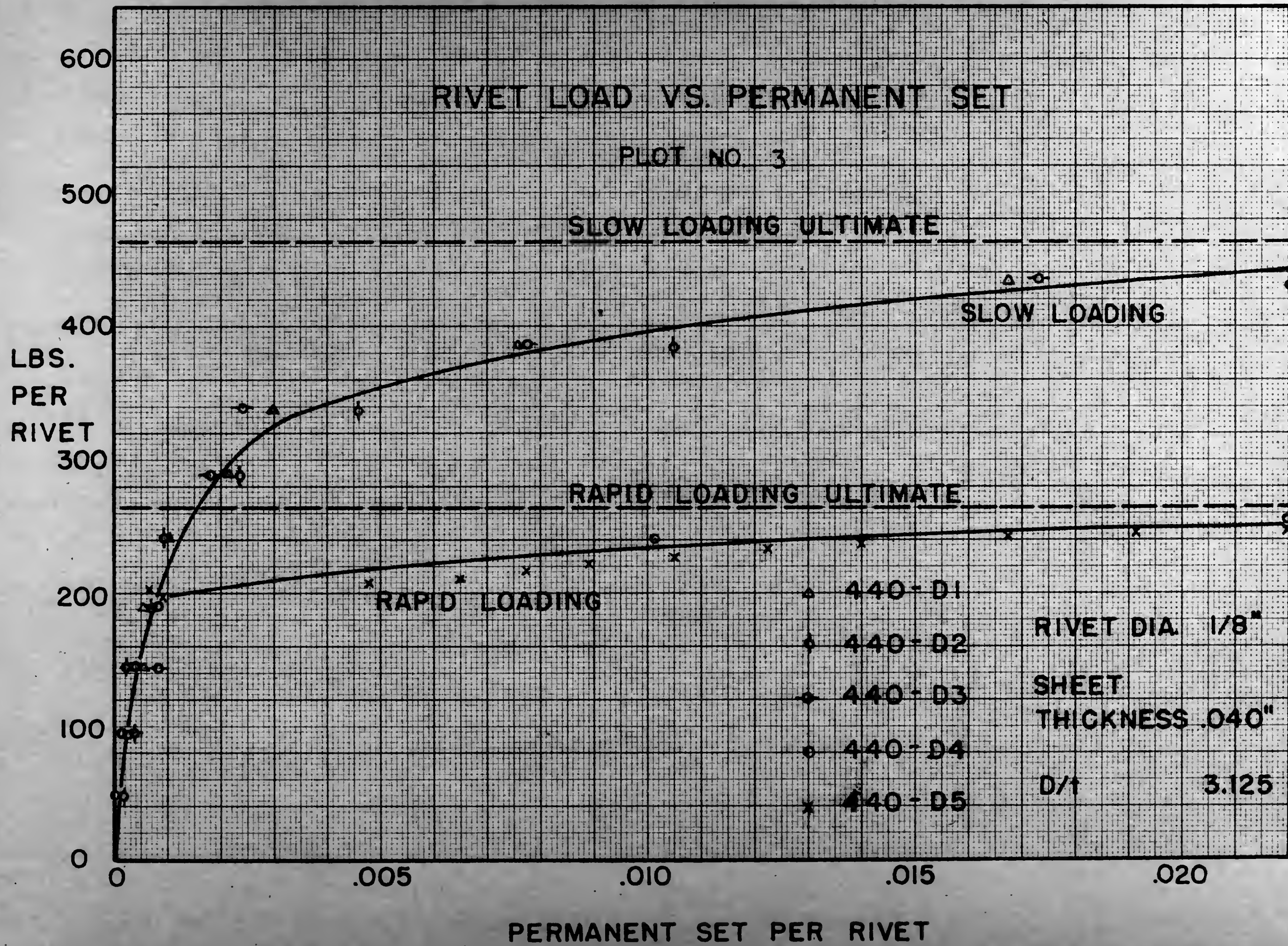
Table III. Comparison of Rapid Load Ultimate

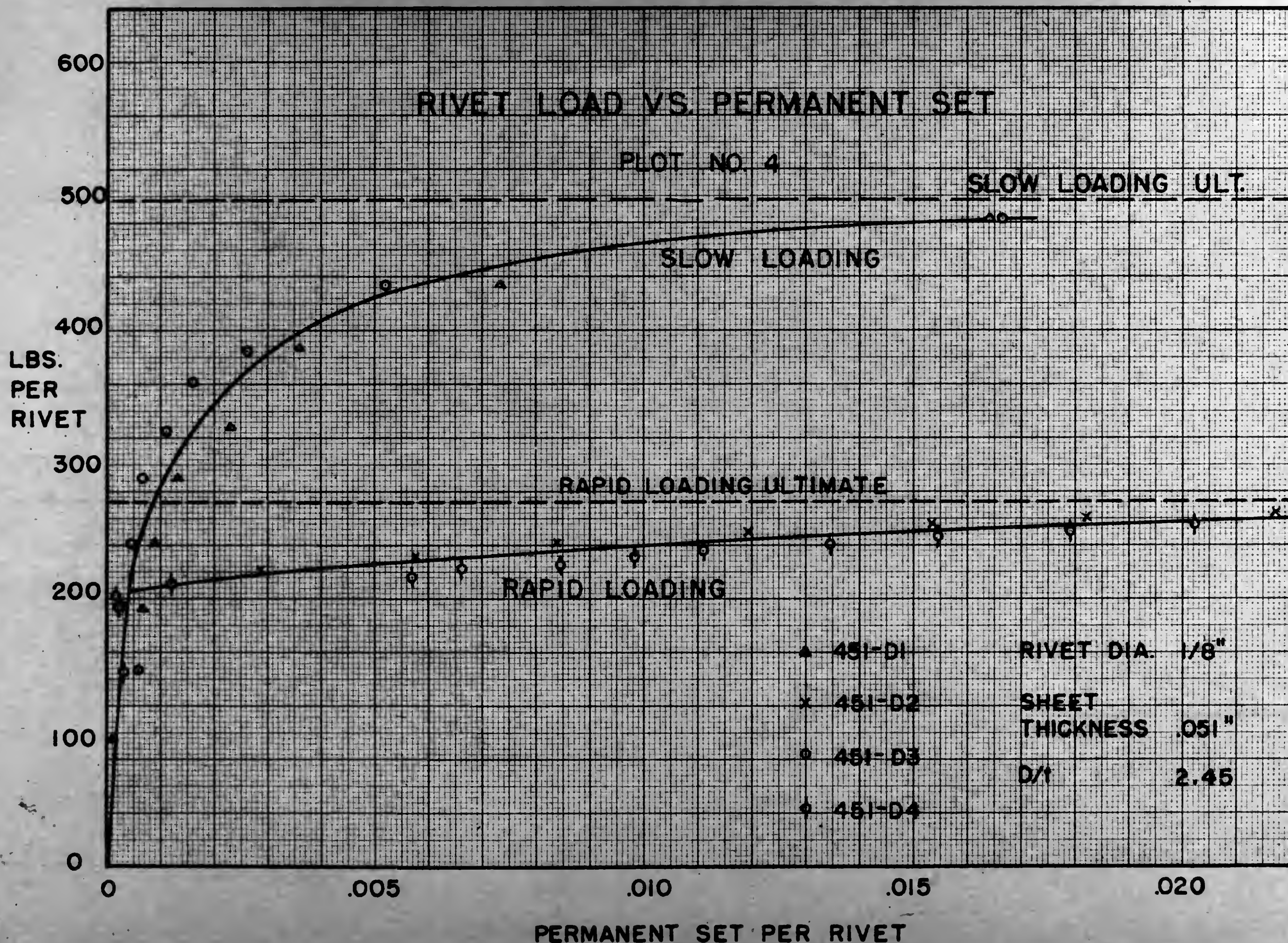
Specimen	440-G	440-D	451-D
% Tested Ultimate	56.9	49.6	39.7
% A.A.I.A. Ultimate	67.1	76.8	70.4
% ANC-5 Ultimate	74.1	84.6	71.5
% A.A.I.A. Yield	116.0	133.0	112.0

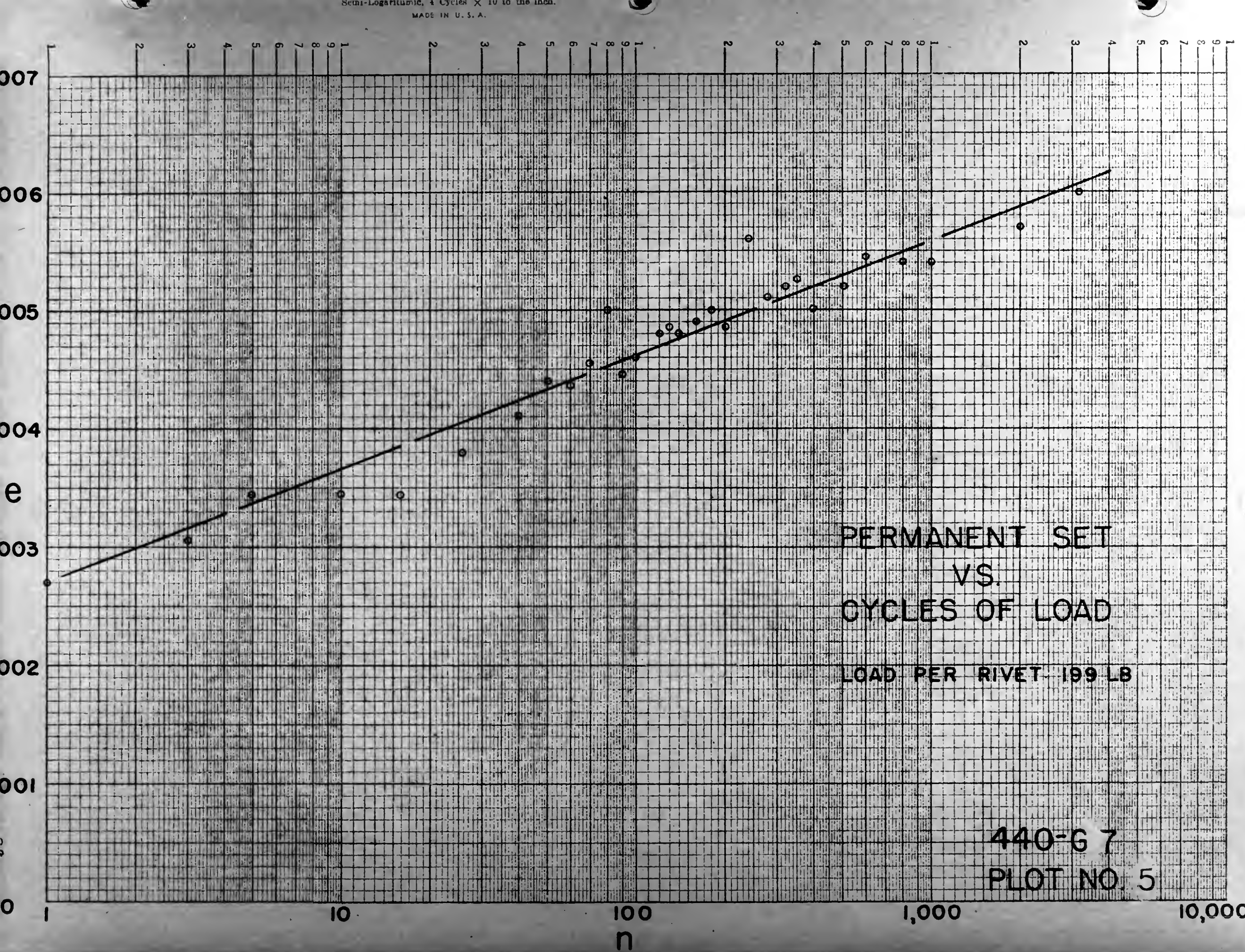

COMPARISION OF SPECIMEN SCATTER
PERMANENT SET PER RIVET
VS.
NUMBER OF CYCLES OF LOAD
LOAD PER RIVET 199 LBS.
e
.007
.006
.005
.004
.003
.002
.001
0
n
1
10
100
1,000
10,000
× 440-G2
● 440-GIL
PLOT NO. 1

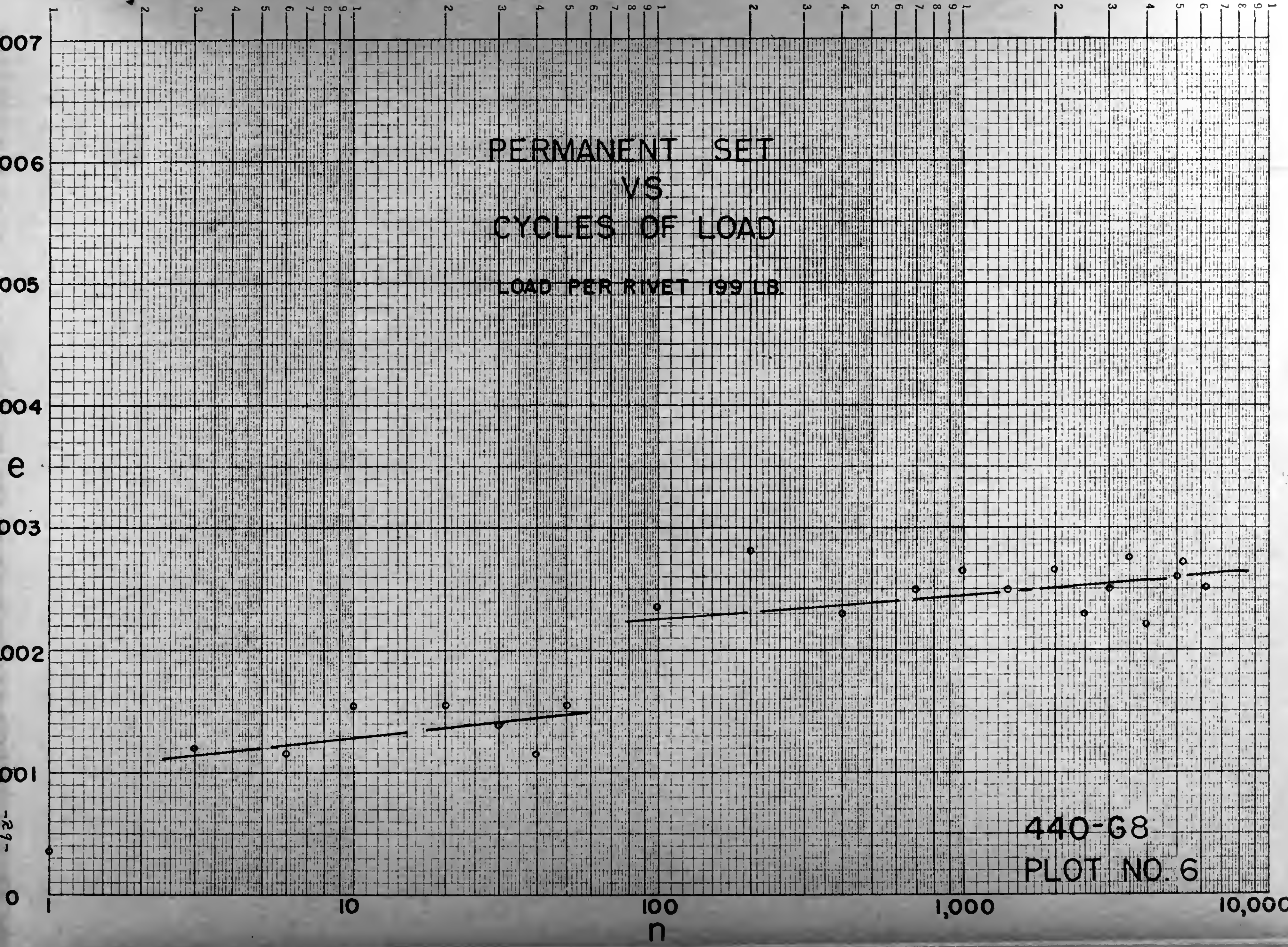


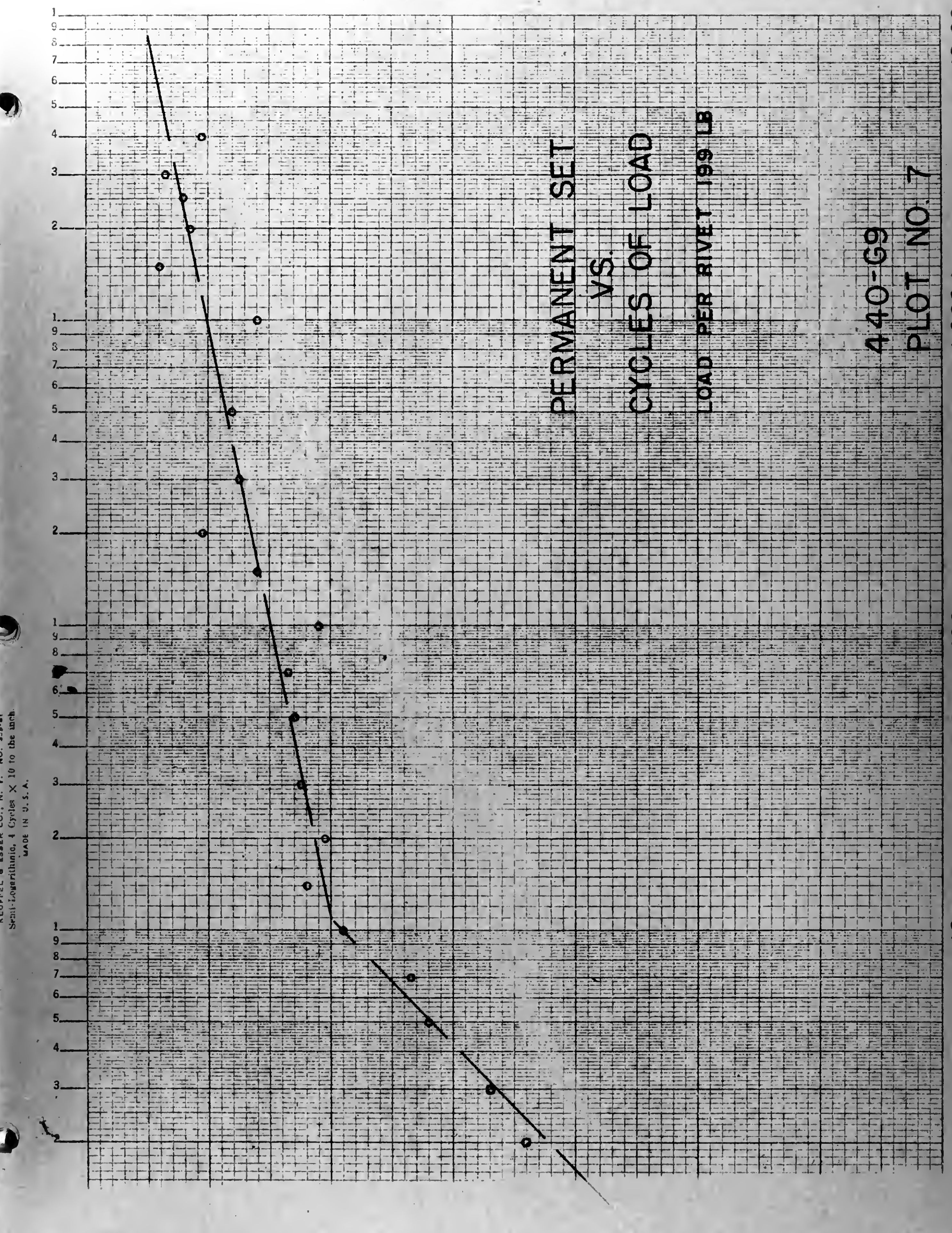
RIVET LOAD VS. PERMANENT SET
PLOT NO. 2
SLOW LOADING ULTIMATE
SLOW LOADING
RAPID LOADING ULTIMATE
RAPID LOADING
440-G3
440-G4
440-G5
440-G6
RIVET DIA. 1/8"
SHEET THICKNESS .040"
D/t 3.124
LBS. PER RIVET
600
500
400
300
200
100
0
0
.005
.010
.015
.020
PERMANENT SET PER RIVET


RIVET LOAD VS. PERMANENT SET
PLOT NO. 3
SLOW LOADING ULTIMATE
SLOW LOADING
RAPID LOADING ULTIMATE
RAPID LOADING
440-D1
440-D2
440-D3
440-D4
440-D5
RIVET DIA. 1/8"
SHEET THICKNESS .040"
D/t 3.125
LBS. PER RIVET
600
500
400
300
200
100
0
0
.005
.010
.015
.020
PERMANENT SET PER RIVET

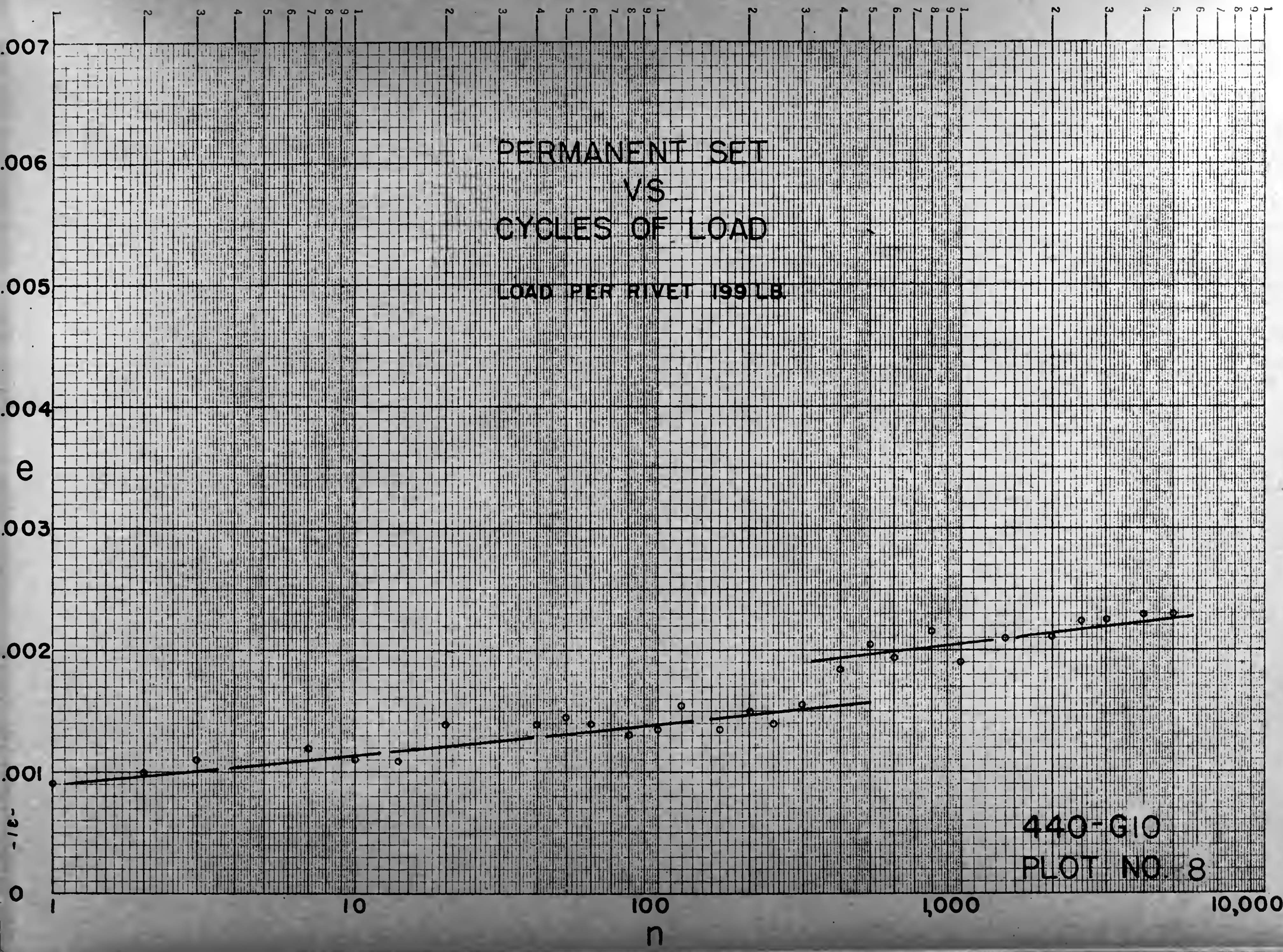

RIVET LOAD VS. PERMANENT SET
PLOT NO. 4
SLOW LOADING ULT.
SLOW LOADING
RAPID LOADING ULTIMATE
RAPID LOADING
451-D1
451-D2
451-D3
451-D4
RIVET DIA. 1/8"
SHEET THICKNESS .051"
D/t 2.45
LBS. PER RIVET
600
500
400
300
200
100
0
.005
.010
.015
.020
PERMANENT SET PER RIVET

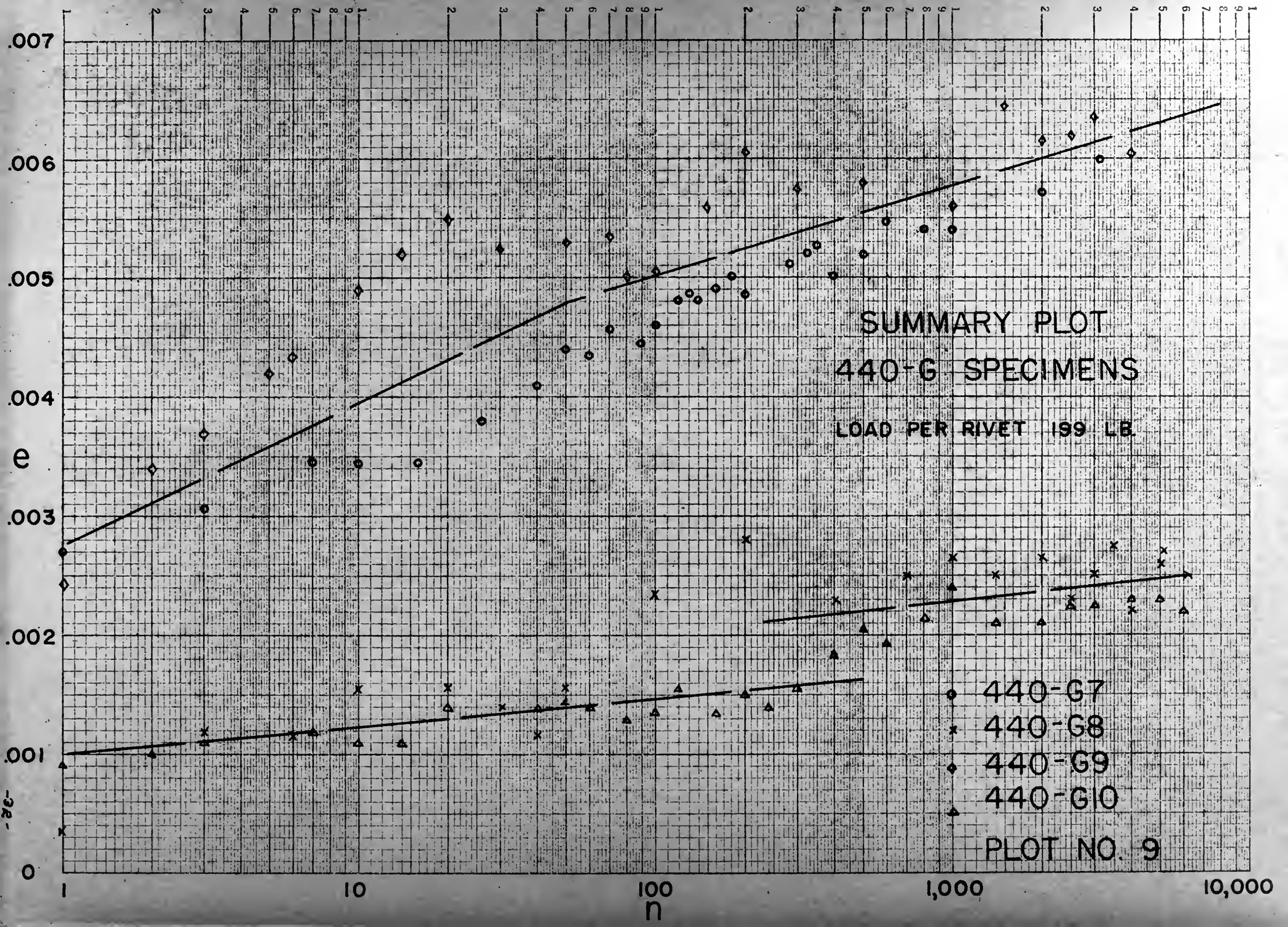

Semi-Logarithmic, 4 Cycles X 10 to the inch.
MADE IN U. S. A.
PERMANENT SET
VS.
CYCLES OF LOAD
LOAD PER RIVET 199 LB
440-G 7
PLOT NO. 5
e
n
.007
.006
.005
.004
.003
.002
.001
0
1
10
100
1,000
10,000

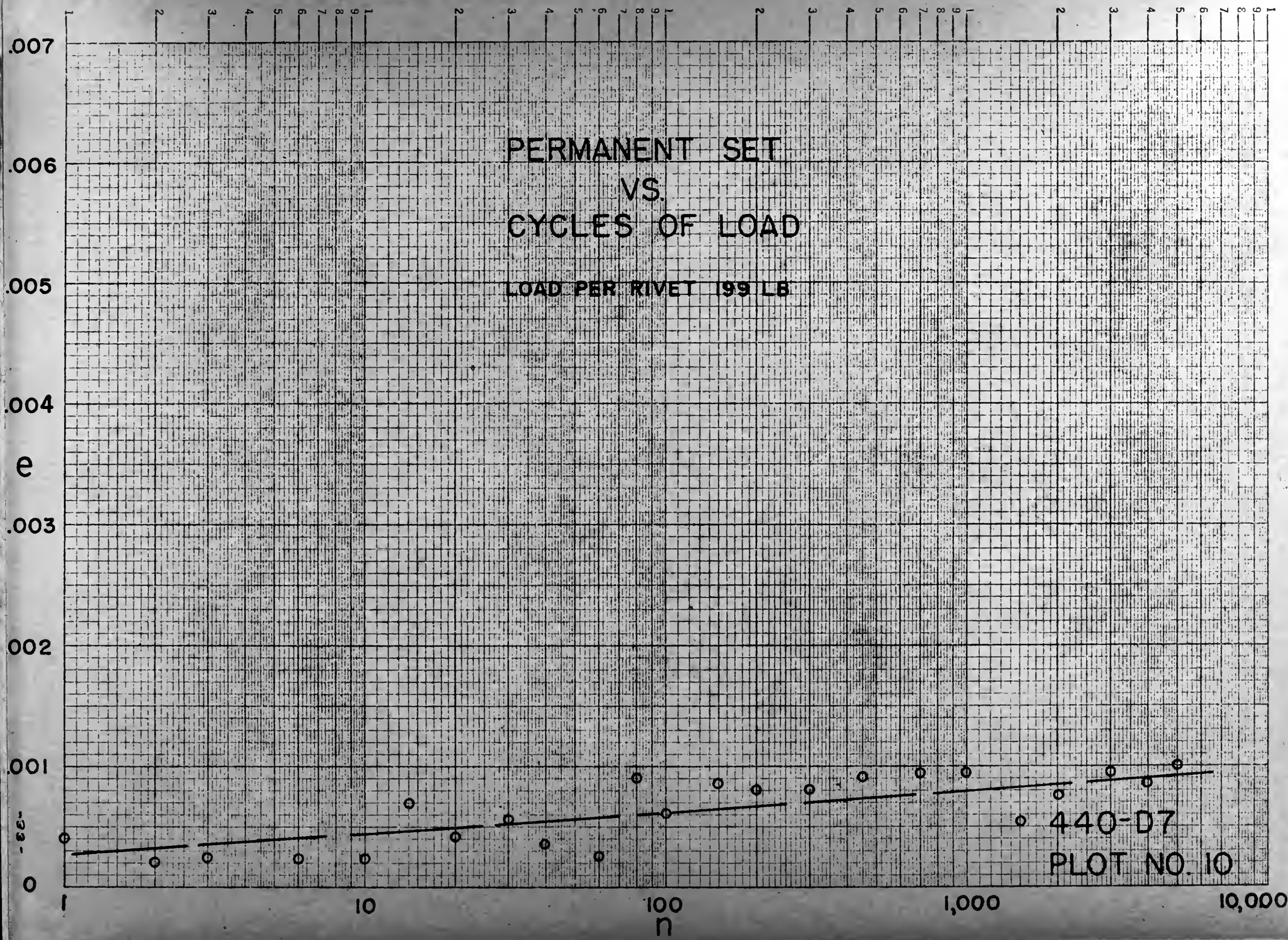

PERMANENT SET
VS.
CYCLES OF LOAD
LOAD PER RIVET 199 LB.
440-G8
PLOT NO. 6
e
n
.007
.006
.005
.004
.003
.002
.001
0
1
10
100
1,000
10,000

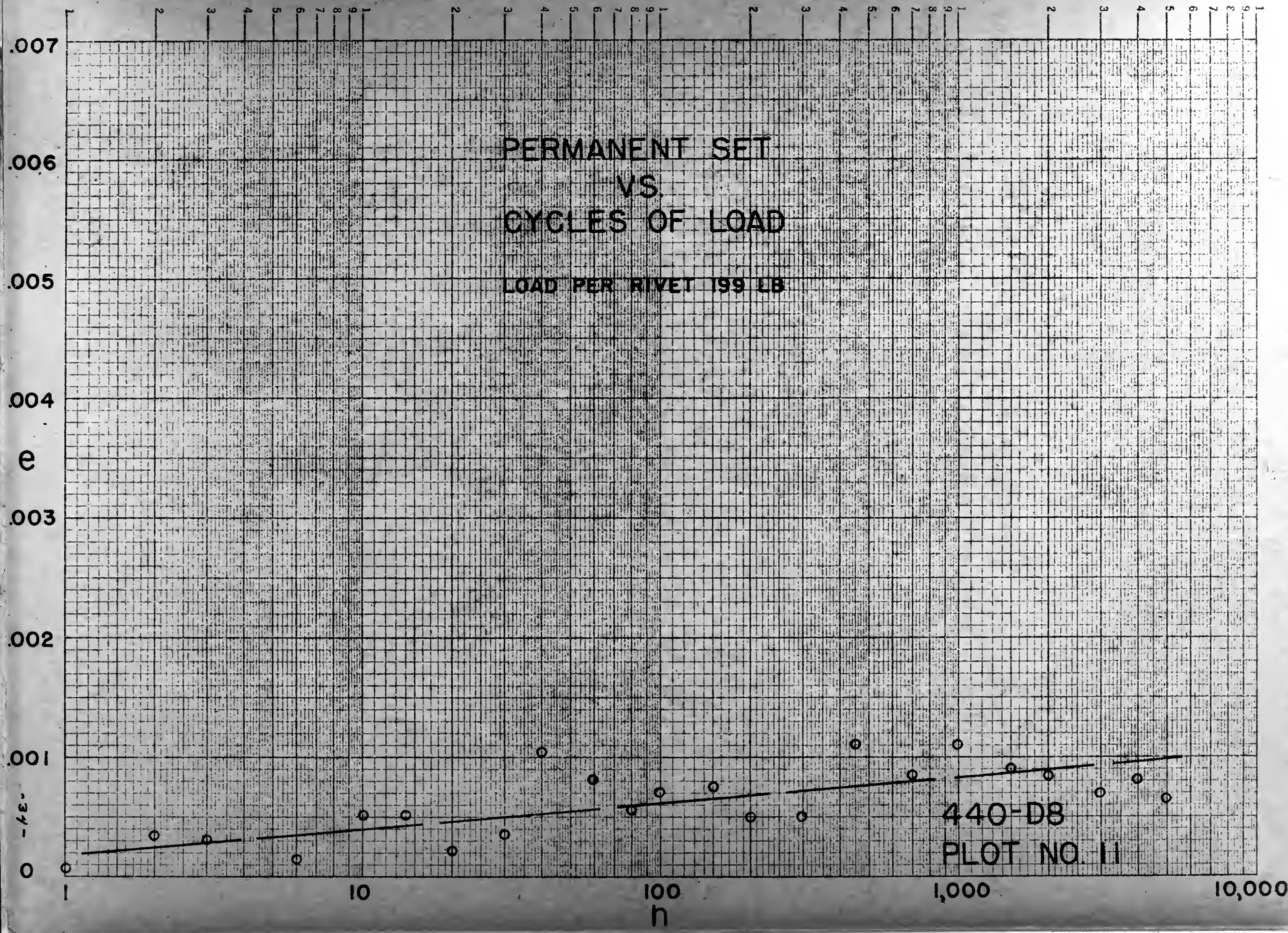

PERMANENT SET
VS.
CYCLES OF LOAD
LOAD PER RIVET 199 LB
440-G9
PLOT NO. 7
10
100
1,000
10,000
n
KEUFFEL & ESSER CO., N. Y. NO. 359-81
Semi-Logarithmic, 4 Cycles X 10 to the inch
MADE IN U.S.A.

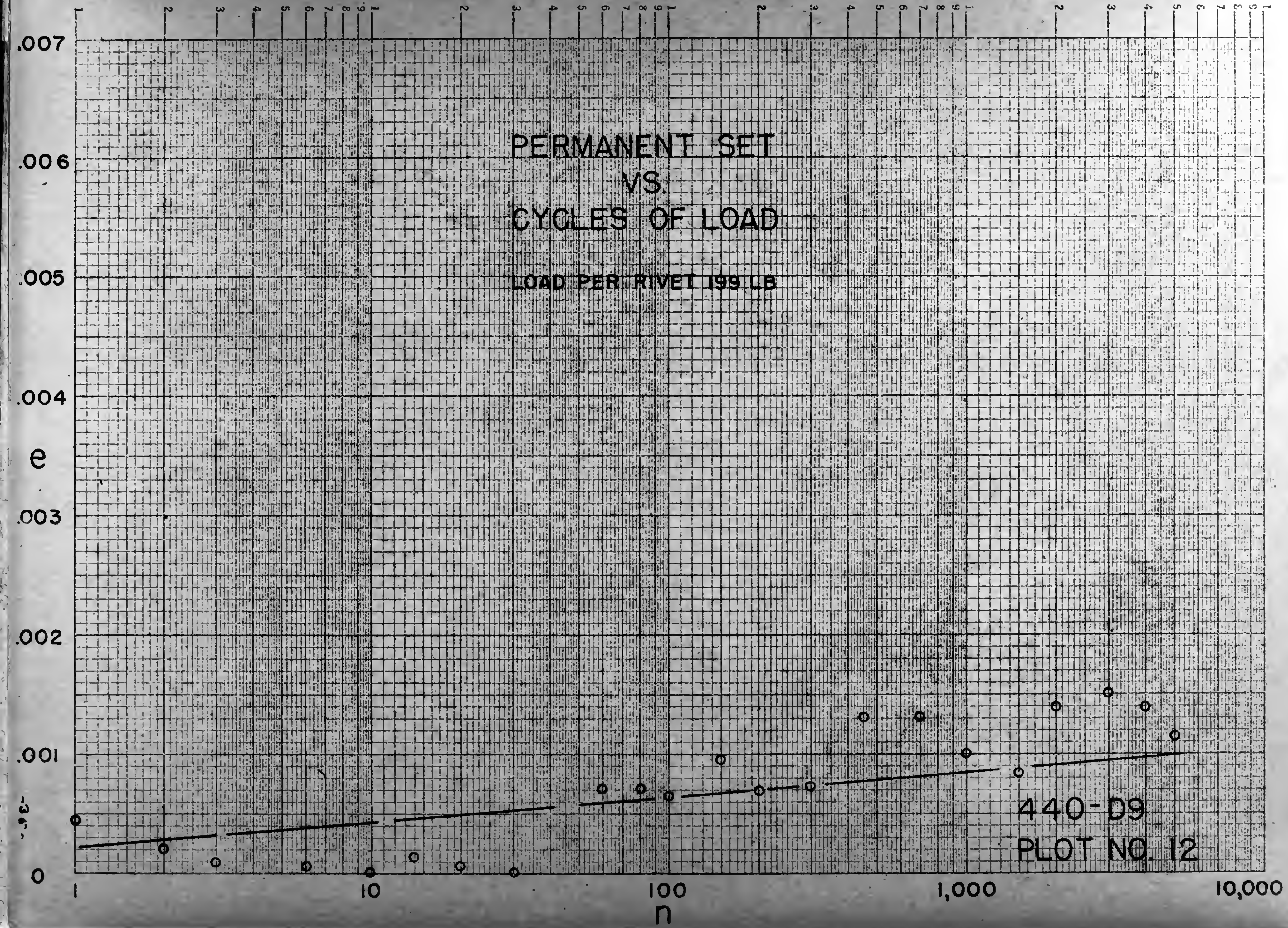
Semi-Logarithmic, 4 Cycles × 10 to the inch.
MADE IN U. S. A.



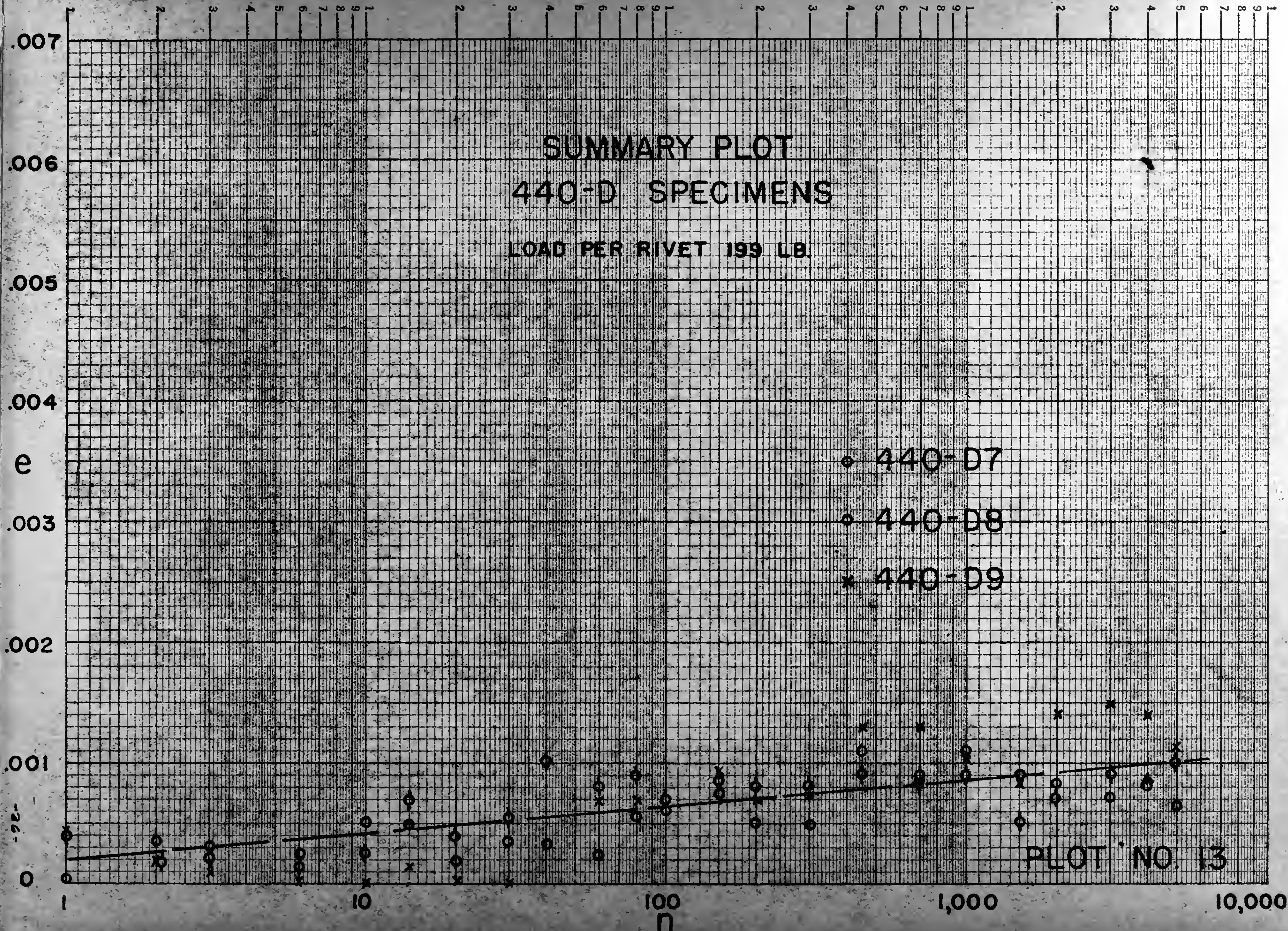

SUMMARY PLOT
440-G SPECIMENS
LOAD PER RIVET 199 LB.
440-G7
440-G8
440-G9
440-G10
PLOT NO. 9
e
n
.007
.006
.005
.004
.003
.002
.001
0
1
10
100
1,000
10,000


PERMANENT SET
VS.
CYCLES OF LOAD
LOAD PER RIVET 199 LB
440-D7
PLOT NO. 10
e
.007
.006
.005
.004
.003
.002
.001
0
n
1
10
100
1,000
10,000


PERMANENT SET
VS.
CYCLES OF LOAD
LOAD PER RIVET 199 LB
440-D8
PLOT NO. 11
.007
.006
.005
.004
e
.003
.002
.001
0
1
10
100
1,000
10,000
n


PERMANENT SET
VS.
CYCLES OF LOAD
LOAD PER RIVET 199 LB
440-D9
PLOT NO. 12
e
n
.007
.006
.005
.004
.003
.002
.001
0
1
10
100
1,000
10,000

Semi-Logarithmic, 4 Cycles × 10 to the inch.
MADE IN U. S. A.



C. Conclusions

The tests conducted indicated that the ultimate strength of riveted joints is dependent upon the time interval required to reach the load imposed upon the joint. This reduction in ultimate strength has no known explanation in terms of the material behavior, and must be attributed to the action of the joint itself. The Guggenheim Laboratory prepared specimens were not manufactured with the best fabricating procedures and control; this fact is reflected in the lower slow loading ultimate of these joints. However, the rapid loading ultimate is only slightly lower than that of the joints prepared by the Douglas Aircraft Company under more desirable manufacturing conditions. The single rivet size and two sheet combinations manufactured by the Douglas Aircraft Company have their rapid loading ultimates within eight pounds of one another. Considering the three specimen groups tested, it appears that the rapid loading ultimate is primarily dependent upon the rivet size, and a further investigation of a greater range of rivet size and sheet thickness combinations should be conducted.

In all specimens tested to ultimate strength, the rivets in the joint failed. In the specimens with .040 sheet material, rivet failure was proceeded by a very marked cocking of the rivet head, as shown in Fig. 21.

This head cocking of the rivet indicated that the head was being deformed by the knife edge action of the sheet as described in Ref. 3, and could be predicted from the D/t ratio of the joint. When specimens with a sheet thickness of .051 were tested no such cocking action of the rivet head prior to failure was evident. In this case a small elongation of the rivet hole in the countersunk sheet was noted, indicating a very small amount of bearing failure was occurring. However, in no case was the deformation of the sheet large enough to be noted until after the rivet had failed, exposing the sheet beneath the countersunk rivet head.

The effect of repeated rapid loads of 199 lbs. per rivet on the riveted joint is shown in Plots five through thirteen. In general, the permanent set of the joint increases slowly with the number of cycles, but no indication that the joint would eventually fail due to effects of the rapid loading was found in so far as the number of cycles of load was repeated. The specimens manufactured by the Guggenheim Laboratories showed the presence of two distinct trends of permanent set, but it is believed that the joints showing the higher permanent set were incorrectly manufactured.

It is recommended that further investigations encompass a complete range of rivet diameter and sheet thickness combinations together with the use of joints fabricated

by numerous manufacturers; the variation of the time interval to reach maximum load should also be included in an effort to fill in the gap of information between a time interval of 0.038 seconds and 3 seconds.

VI. REFERENCES

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2. Hartmann, E. C., Lyst, J. O., and Andrews, H. J.: Fatigue Tests of Riveted Joints. Progress Report of Tests of 17S-T and 53S-T Joints, NACA Wartime Report, September 1944.
3. ARC Rivet and Screw Allowables Subcommittee: Report on Flush Riveted Joint Strength. Aircraft Industries Association of America, Inc. (Airworthiness Project 12) April 1946.
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10. Gottlieb, R. and Mandel, M. W.: Comparison of Tightness of 70° Machine-countersunk Rivets Driven in Holes Prepared with 78° and 82° Countersinking Tools. NACA Wartime Report L-252, Sept. 1942.

11. Repeated Loads above the Proportional Limit of 24-ST Aluminum Alloy. Thesis by Lt. Cdr. L. G. Bull and Lt. Cdr. R. L. Mastin, 1947. (California Institute of Technology)

VII ILLUSTRATIONS

A. Specimens

Fig. 1 Typical Flush Rivet Specimen
Fig. 2 Rivet Joint Test Specimen
Fig. 3 Rivet Joint Test Specimen

B. Testing Machine

Fig. 4 Repeated Load Hydraulic Testing Machine
Fig. 5 Top View of Testing Machine
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Fig. 7 Electrical Diagram for Repeated Loading Hydraulic Testing Machine
Fig. 8 Repeated Load Hydraulic Testing Machine
Fig. 9 Specimen Attachments and Traveling Microscope

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Fig. 11 Load vs Time Trace
Fig. 12 Load vs Time Trace
Fig. 13 Load vs Time Trace
Fig. 14 Load vs Time Trace
Fig. 15 Load vs Time Trace
Fig. 16 Load vs Time Trace
Fig. 17 Strain Gauge Mounted on 440-D Specimen
Fig. 18 Strain Gauge Mounted Specimen in Testing Machine
Fig. 19 Electronics Equipment for Determining Load vs. Time Trace
Fig. 20 Electronics Apparatus Schematic

D. Typical Specimen Results

Fig. 21 Permanent Set or "Slip" in Countersunk Rivet Joint just Prior to Failure
Fig. 22 Typical Countersunk Rivet Joint Failure

TYPICAL FLUSH RIVET SPECIMEN
MACHINE COUNTER SUNK

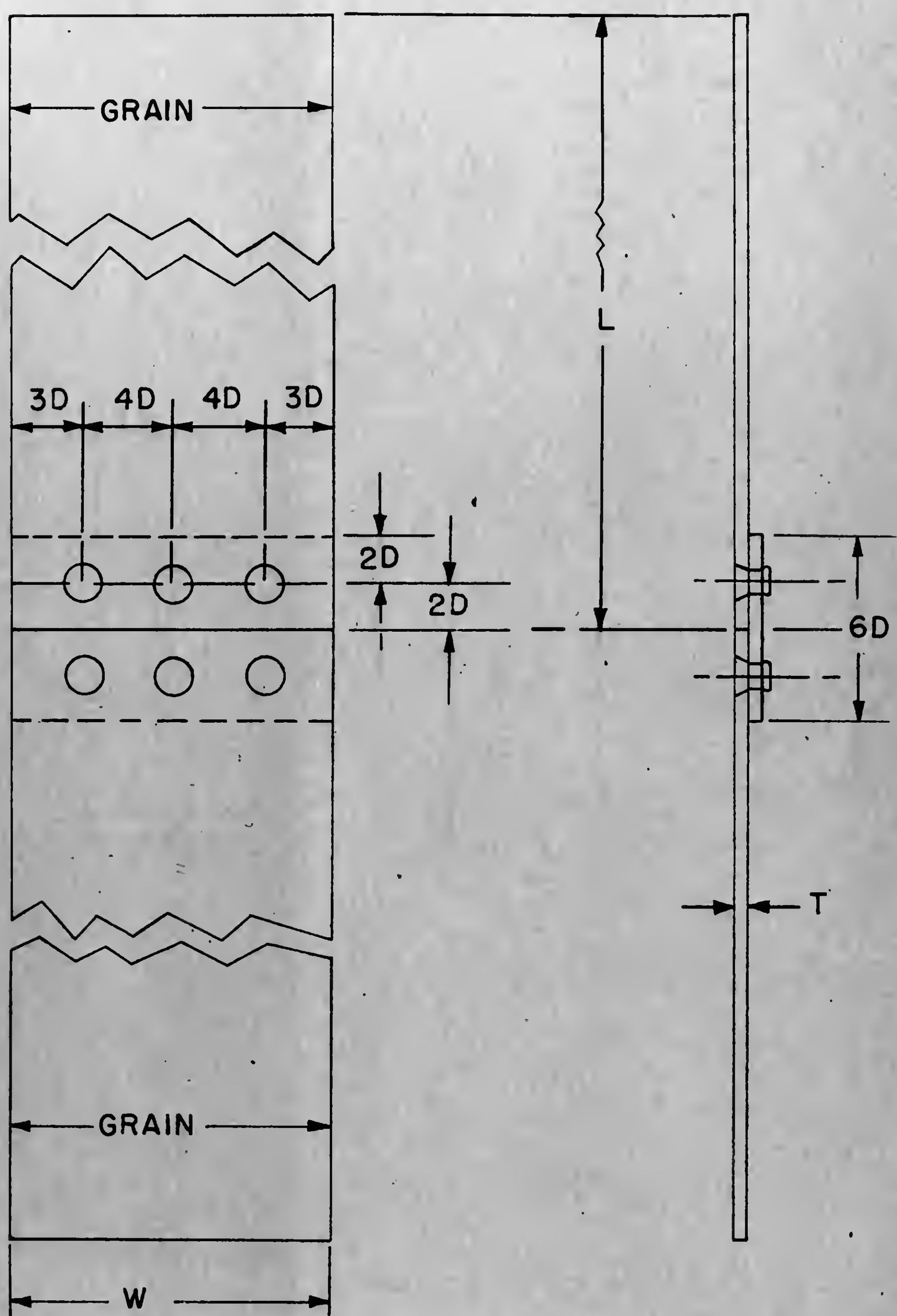


FIG. I

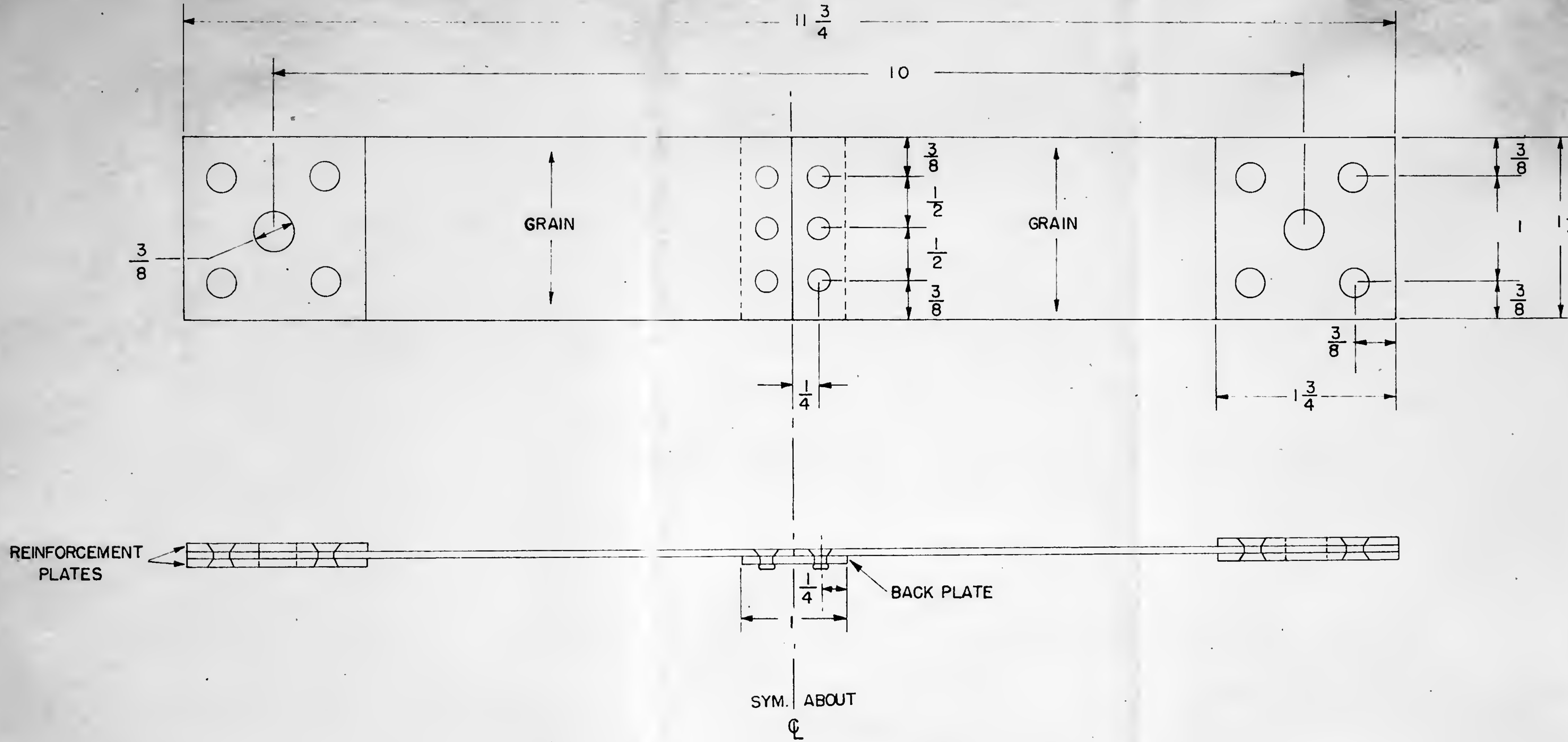


FIG. 2

RIVET SPECIFICATIONS

a. JOINT– 100° FLUSH HEAD RIVETS INSTALLED IN MACHINE COUNTERSUNK HOLES

b. REINFORCEMENT PLATE– COUNTERSUNK AND FLUSH RIVETED ON BOTH SIDES – $\frac{5}{32}$ DIA. RIVETS

c. MATERIAL– A17 ST (AD) RIVETS

TYPE	A	C
NUMBER OF SPECIMENS	15	15
SHEET THICKNESS	.040	.051
BACK PLATE SHEET THICKNESS	.051	.064
REINFORCEMENT PLATE THICKNESS	.064	.051
RIVET DIAMETER	$\frac{1}{8}$	$\frac{1}{8}$

MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER
24 ST			[illegible]			

TOLERANCES ± .010 OR $\frac{1}{64}$ UNLESS OTHERWISE NOTED

SCALE FULL

REF.

GUGGENHEIM AERONAUTICAL LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

RIVET JOINT TEST SPECIMEN

NAME

DRAWING NO.

DIEPO 1000H CLEARPRINT

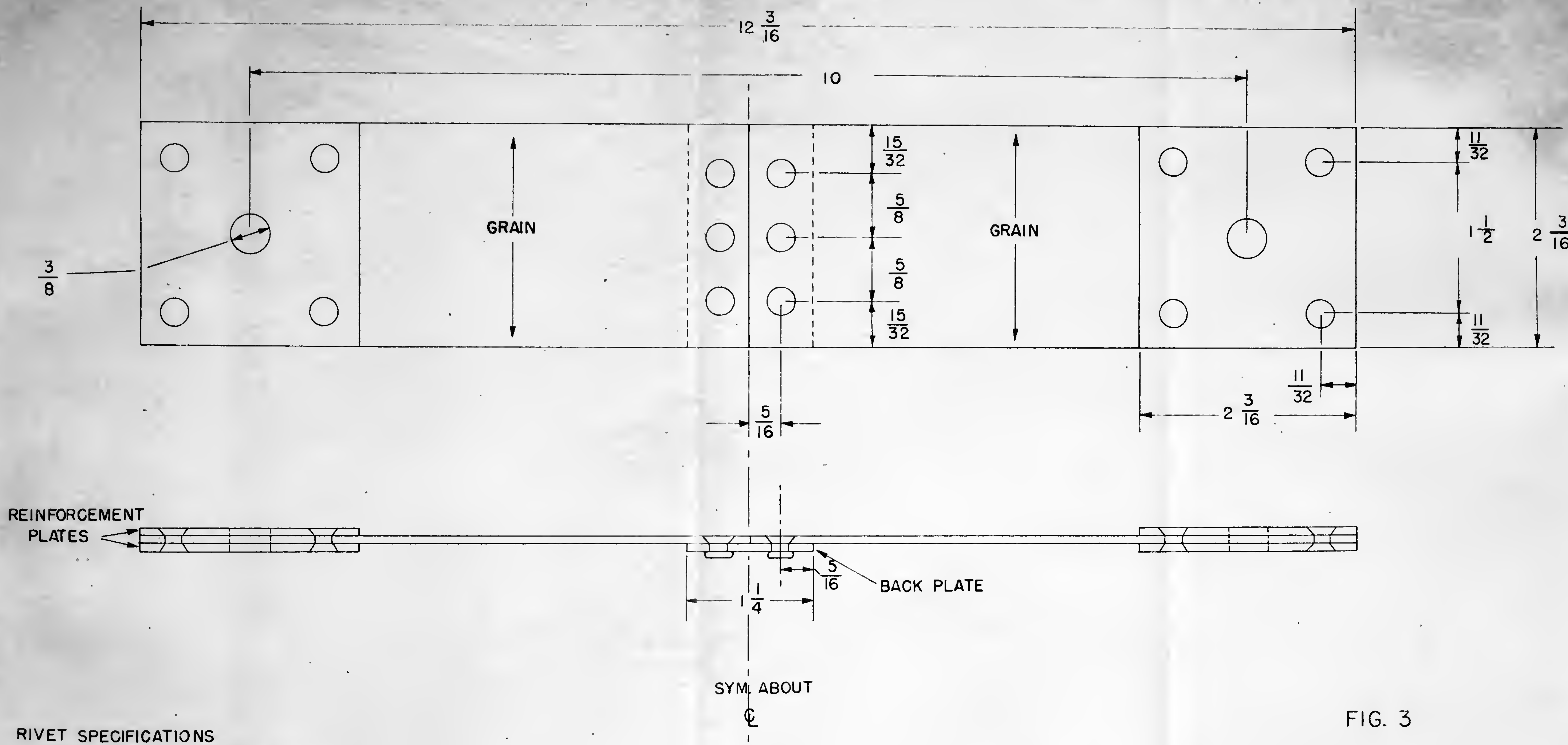


FIG. 3

RIVET SPECIFICATIONS

a. JOINT – 100° FLUSH HEAD RIVETS INSTALLED IN MACHINE COUNTERSUNK HOLES

b. REINFORCEMENT PLATE — COUNTERSUNK AND FLUSH RIVETED ON BOTH SIDES — $\frac{5}{32}$ DIA. RIVETS

c. MATERIAL — A 17 ST (AD) RIVETS

TYPE	B	D
NUMBER OF SPECIMENS	15	15
SHEET THICKNESS	.040	.051
BACK PLATE SHEET THICKNESS	.051	.064
REINFORCEMENT PLATE THICKNESS	.064	.051
RIVET DIAMETER	$\frac{5}{32}$	$\frac{5}{32}$

MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER
24 ST						

TOLERANCES ± .010 OR $\frac{1}{64}$ UNLESS OTHERWISE NOTED

SCALE FULL

REF.

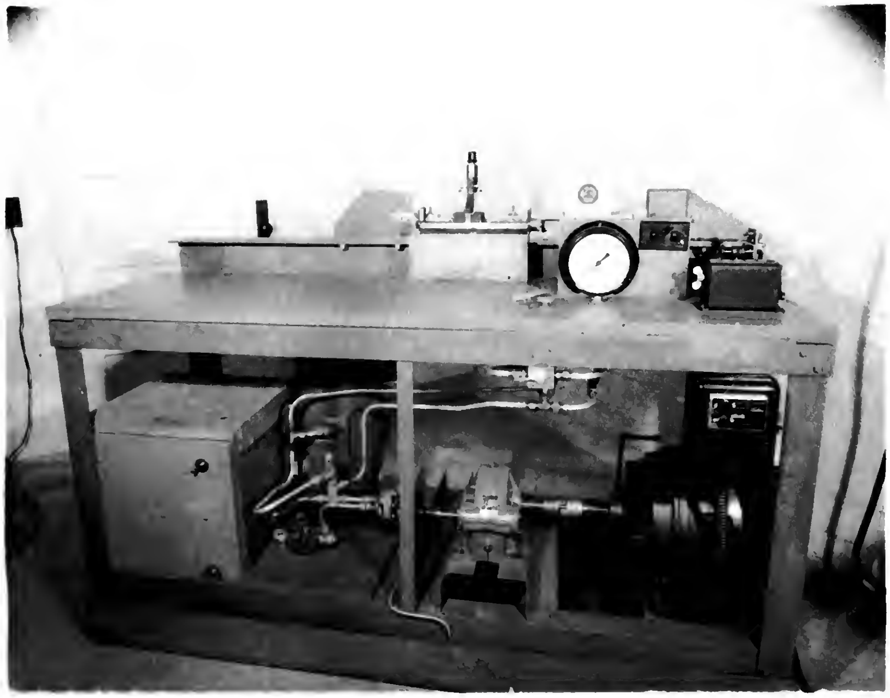
GUGGENHEIM AERONAUTICAL LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

RIVET JOINT
TEST SPECIMEN

NAME

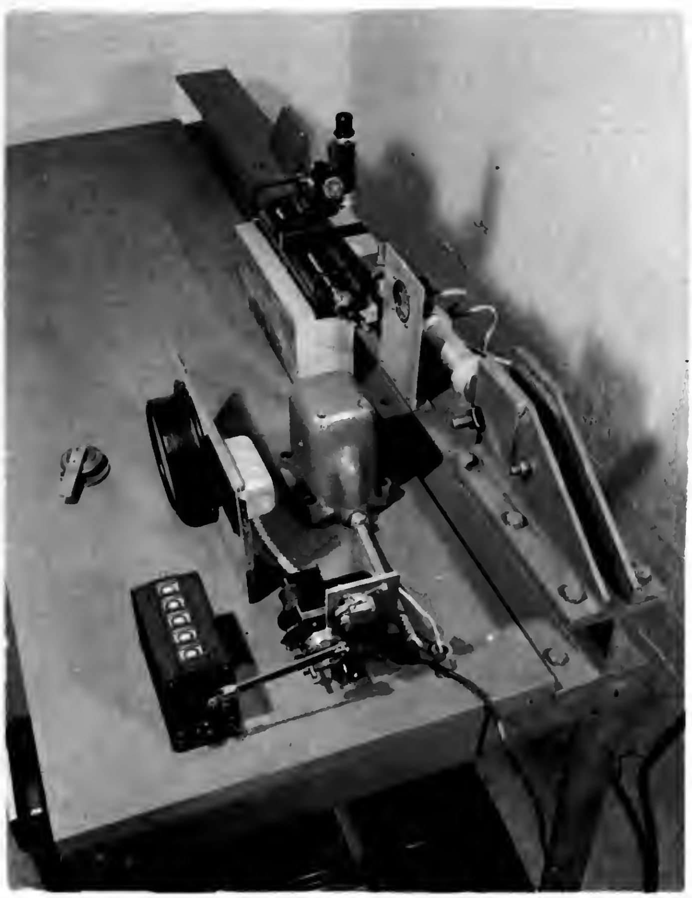
DRAWING NO.

DIEPO 1000H CLEARPRINT



Repeated Load Hydraulic Testing Machine.

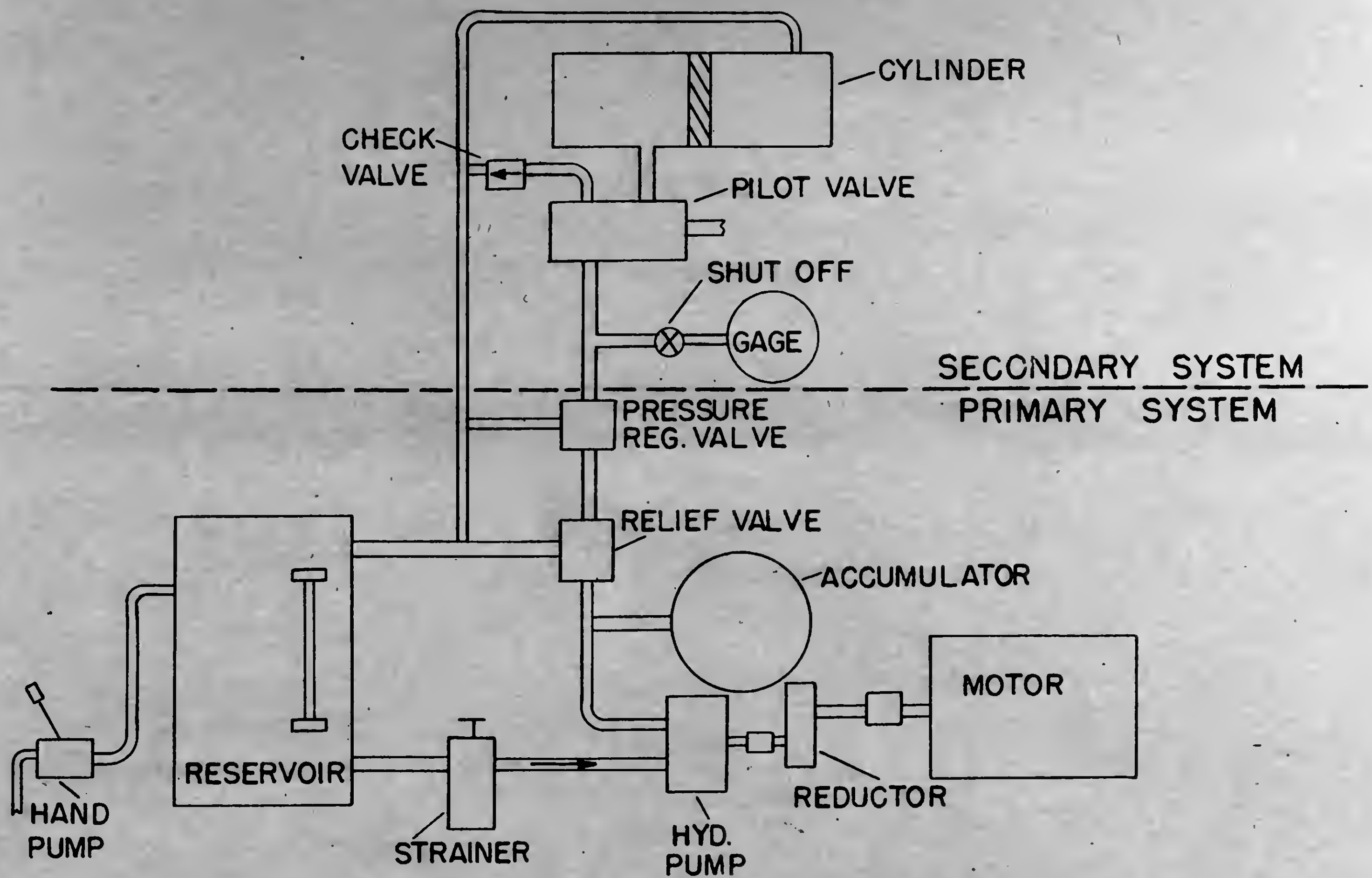
FIG. 4



Top View of

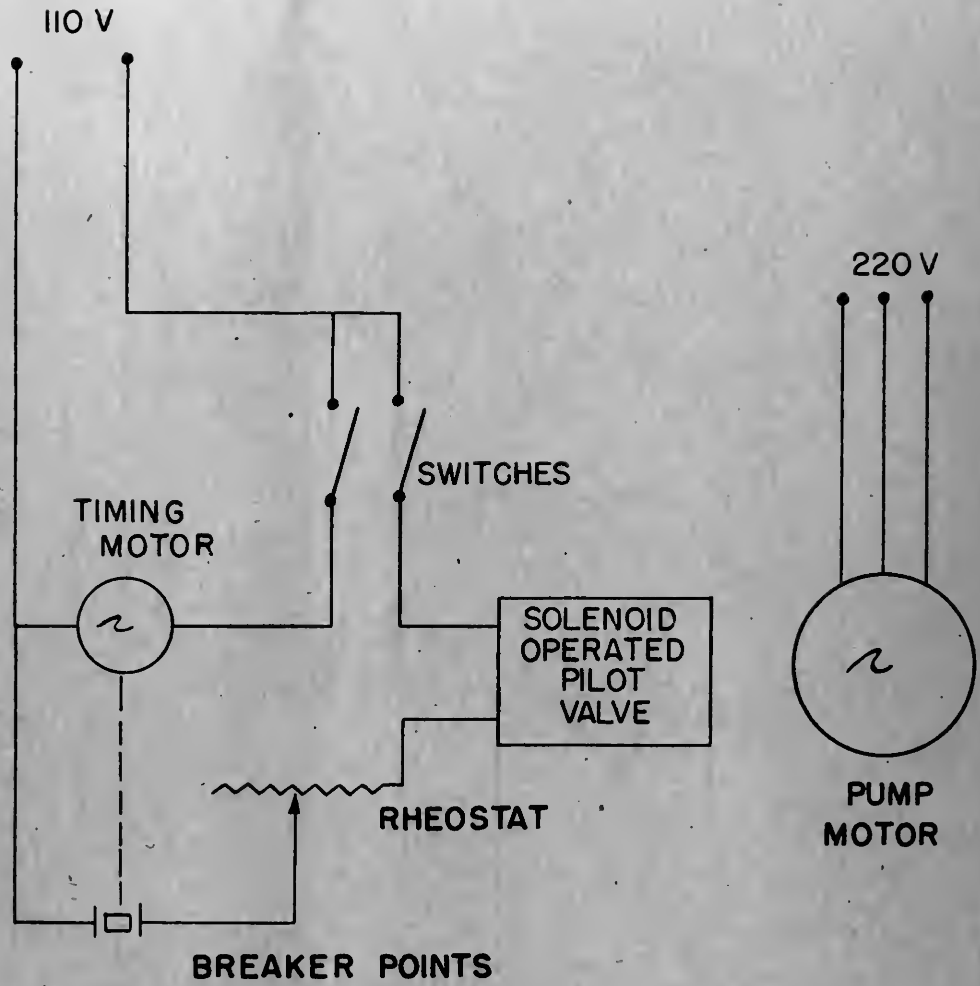
Testing Machine.

FIG. 5



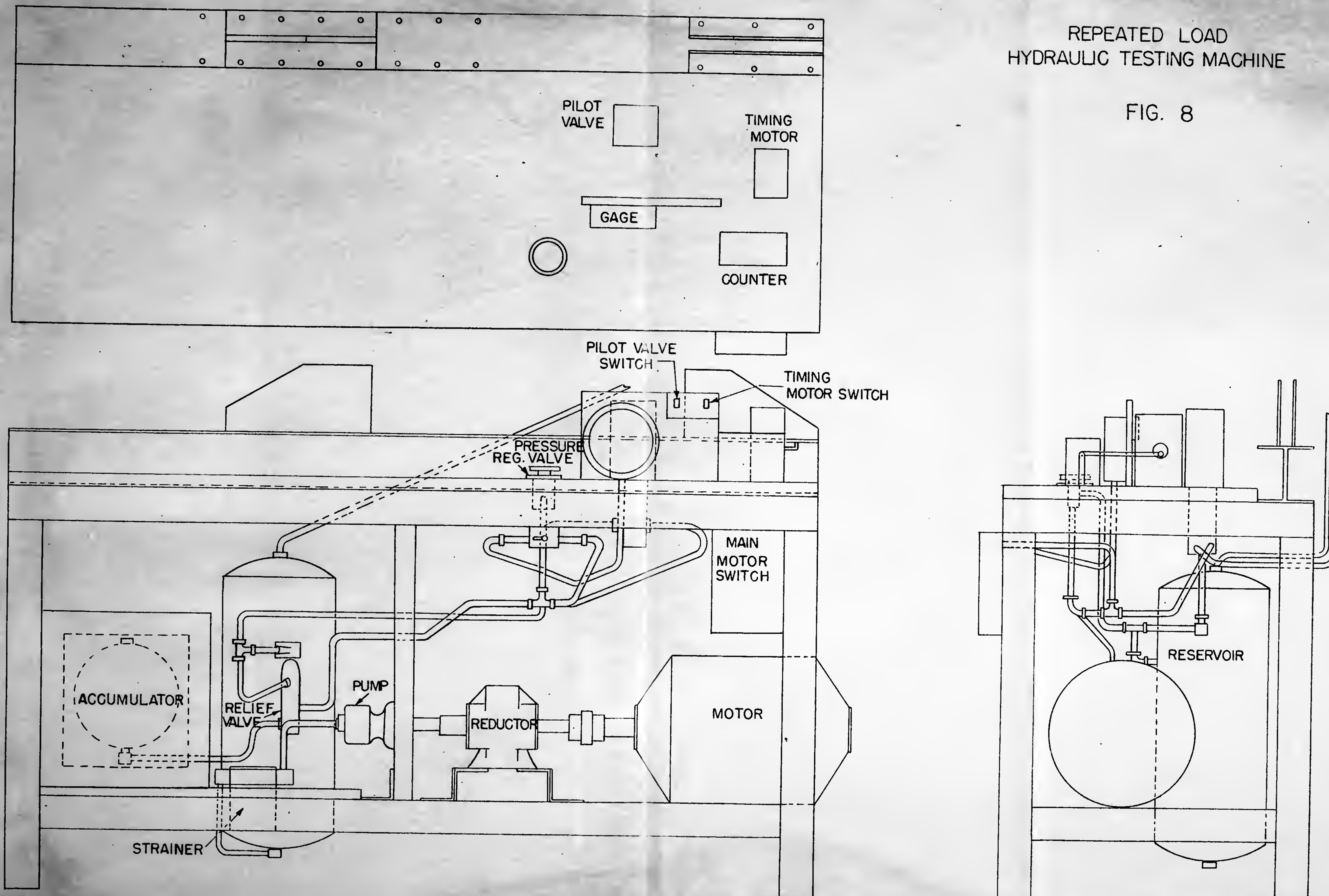
SCHEMATIC DRAWING OF HYDRAULIC SYSTEM

FIG. 6



ELECTRICAL DIAGRAM
FOR
REPEATED LOADING
HYDRAULIC TESTING
MACHINE

FIG. 7



REPEATED LOAD
HYDRAULIC TESTING MACHINE

FIG. 8

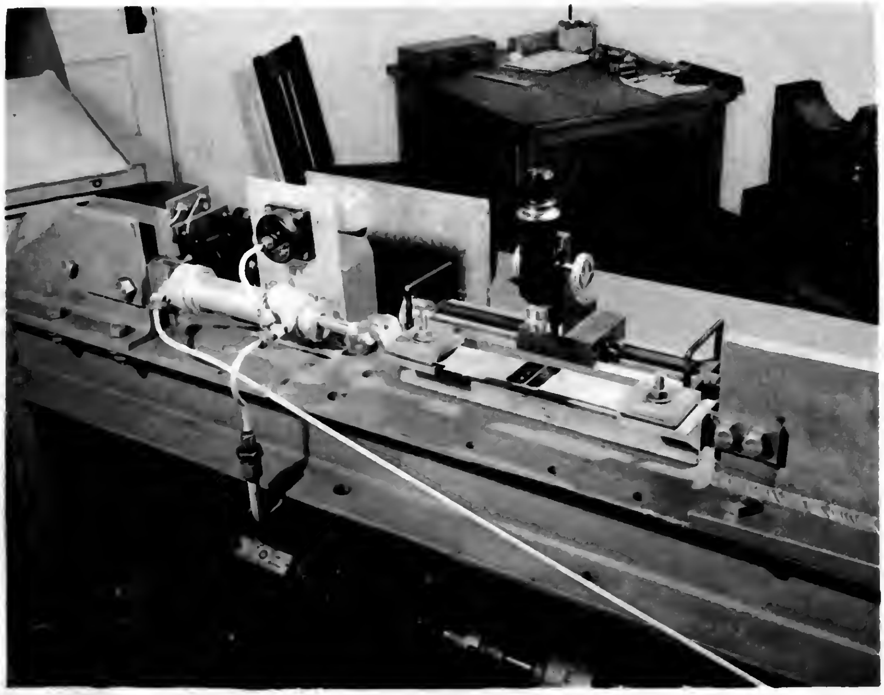
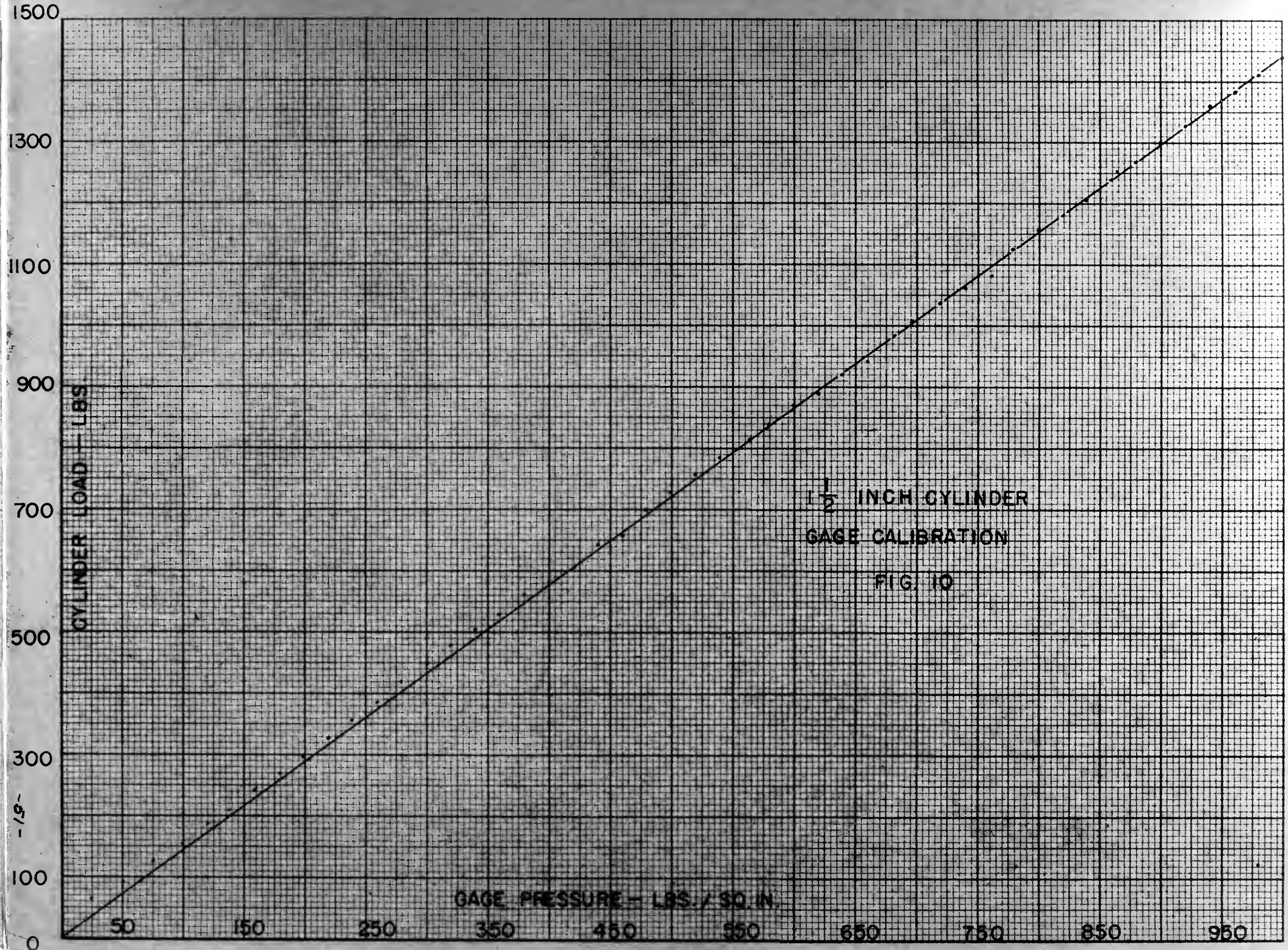
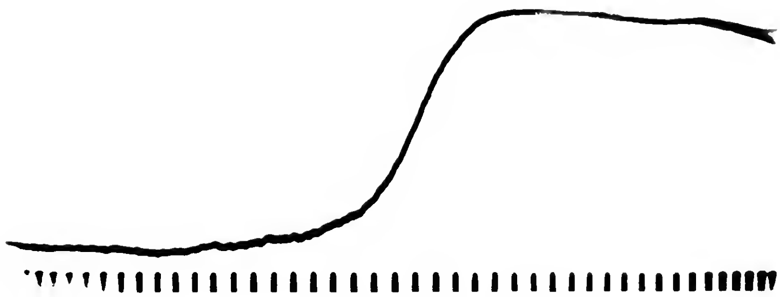


FIG. 9 Specimen Attachments and Traveling Microscope.



$1\frac{1}{2}$ INCH CYLINDER
GAGE CALIBRATION
FIG. 10

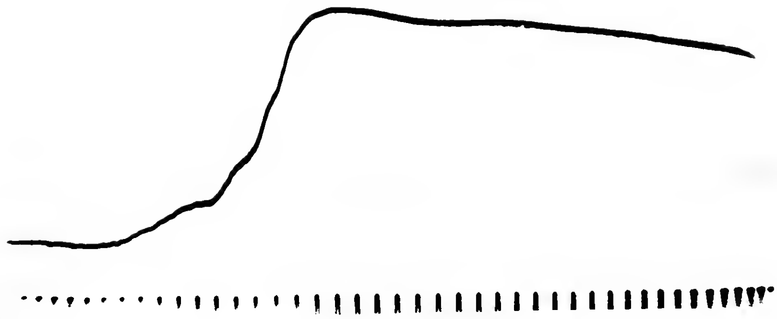


Load vs. Time Trace.
Max. Load--145#/Rivet

FIG. 11

Load vs. Time Trace.
Max. Load--169#/Rivet

FIG. 12

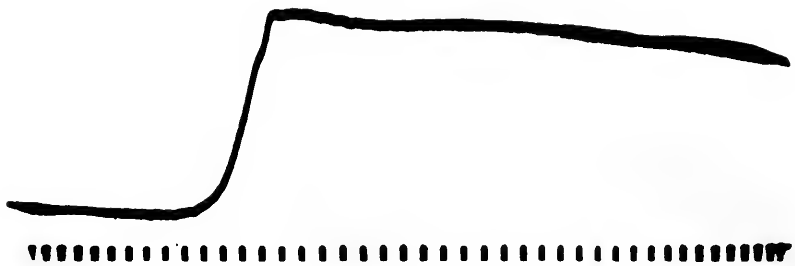


Load vs. Time Trace.
Max. Load--193#/Rivet

FIG. 13

Load vs. Time Trace.
Max. Load--198#/Rivet

FIG. 14

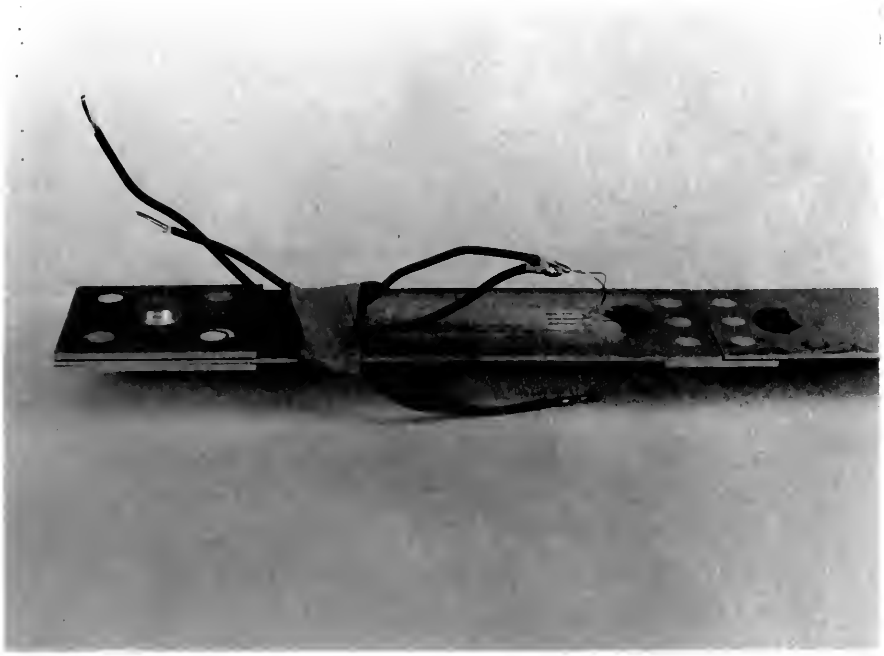


Load vs. Time Trace.
Max. Load--203#/Rivet

FIG. 15

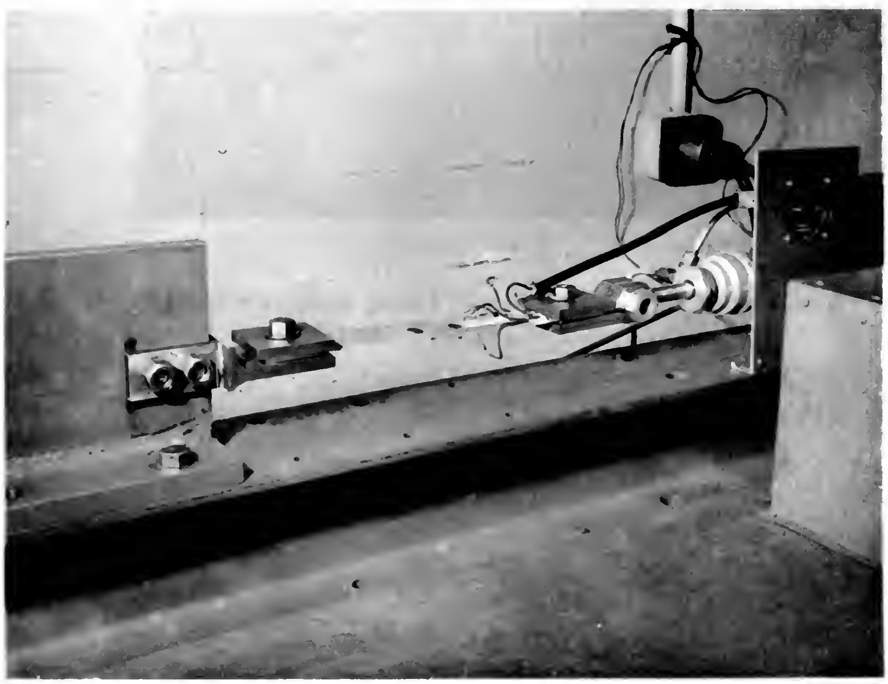
Load vs. Time Trace.
Max. Load--208#/Rivet

FIG. 16



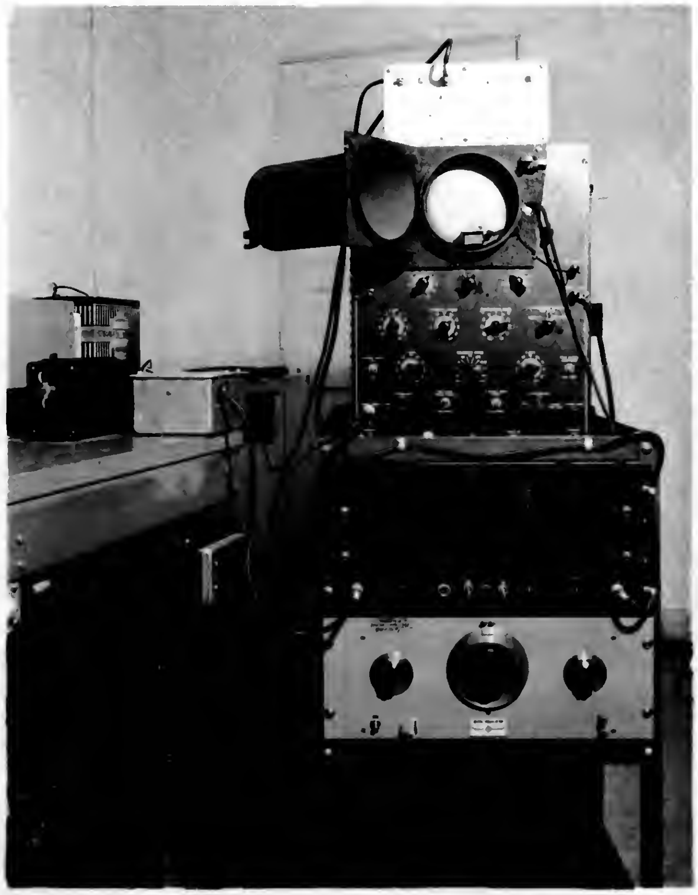
Strain Gauge Mounted on
440-D Specimen.

FIG. 17



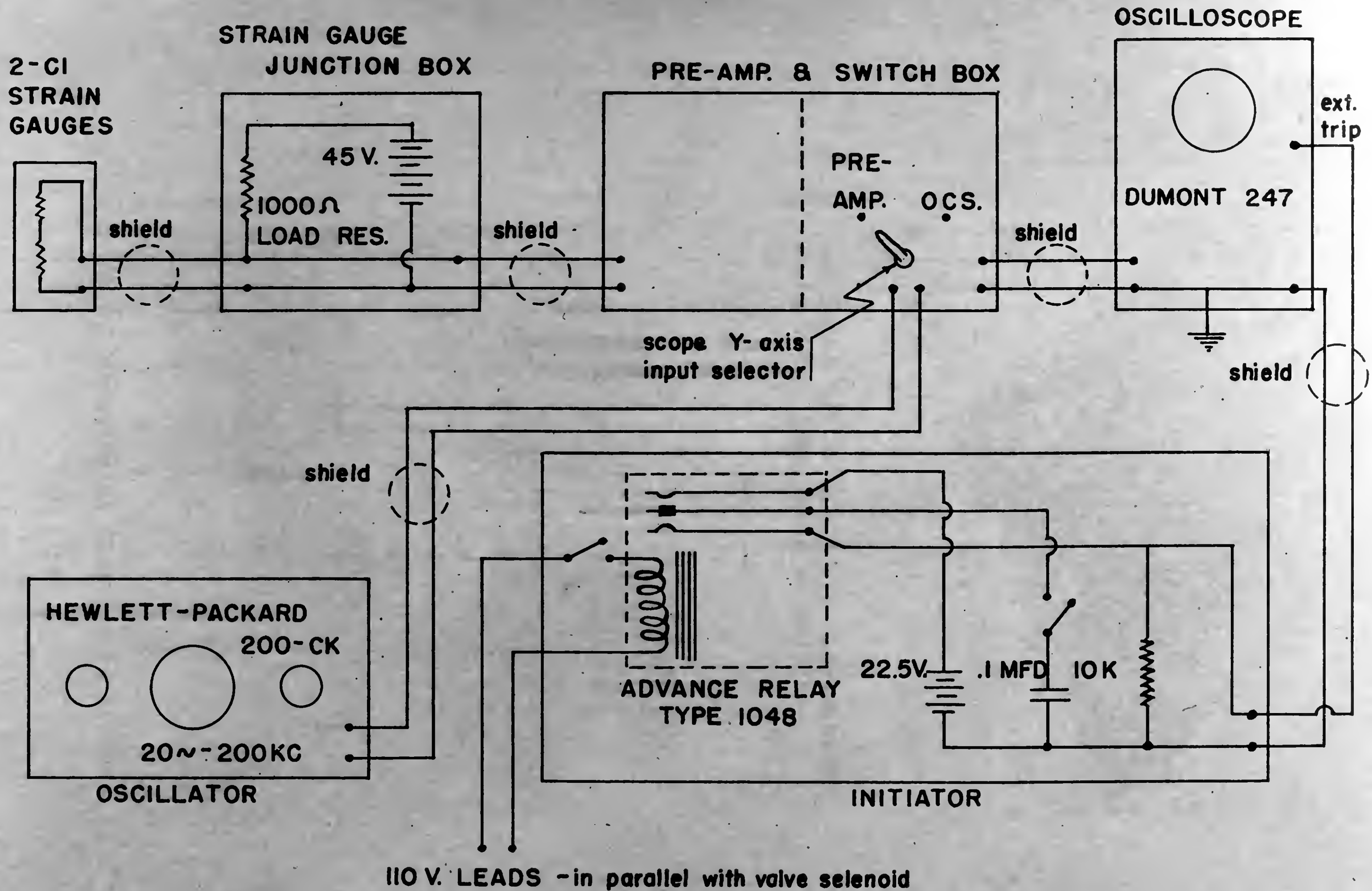
Strain Gauge Mounted Specimen
in Testing Machine.

FIG. 18



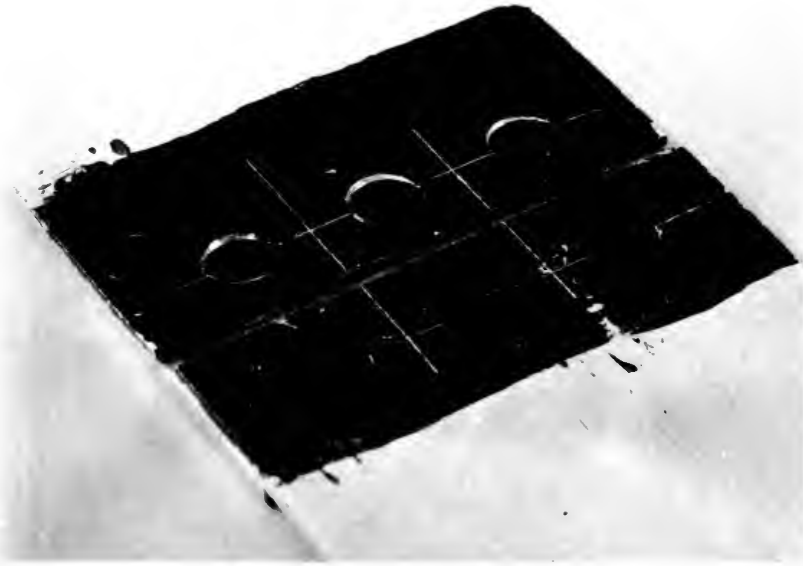
Electronics Equipment for Determining Load vs. Time Trace.

FIG. 19



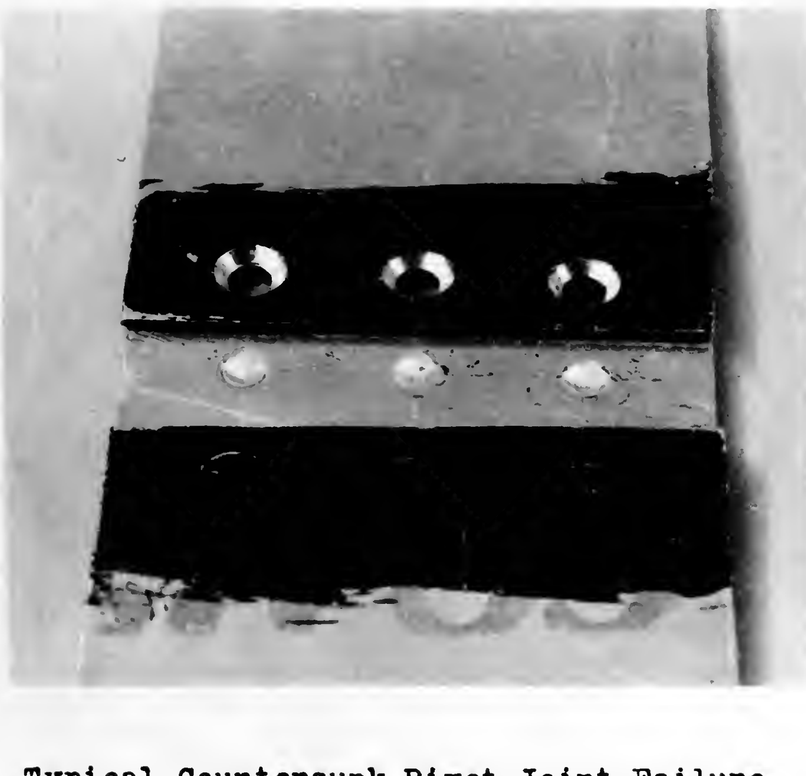
ELECTRONICS APPARATUS SCHEMATIC

FIG. 20



Permanent Set or "Slip" in Countersunk Rivet Joint just Prior to Failure.

FIG. 21



Typical Countersunk Rivet Joint Failure.

FIG. 22

Thesis 8101
S664 Soli
A study of the effects of rapidly applied loads and repeated loads on countersunk riveted joints.